NASA TM X-58168
JSC-09930

PROCEEDINGS OF THE

NASA Earth Resources Survey Symposium

HOUSTON, TEXAS
JUNE 1975

FIRST COMPREHENSIVE SYMPOSIUM ON THE PRACTICAL APPLICATION OF EARTH RESOURCES SURVEY DATA

ORIGINAL CONTAINS COLOR ILLUSTRATIONS

Original photography may be purchased from:
EROS Data Center
10th and Dakota Avenue
Sioux Falls, SD 57198

VOLUME I-A

TECHNICAL SESSION PRESENTATIONS

AGRICULTURE – ENVIRONMENT

National Aeronautics and Space Administration
LYNDON B. JOHNSON SPACE CENTER

NASA TM X-58168

NASA ERSS Earth Resources Survey Symposium

VOLUME I-A

TECHNICAL SESSION PRESENTATIONS

Agriculture
Environment

PREFACE

The first comprehensive symposium on the practical application of Earth resources survey data was sponsored by the NASA Headquarters Office of Applications from June 9 to 12, 1975, in Houston, Texas. The Lyndon B. Johnson Space Center acted as host.

This symposium combined the utilization and results of data from NASA programs involving LANDSAT, the Skylab Earth resources experiment package, and aircraft, as well as from other data acquisition programs.

The primary emphasis was on the practical applications of Earth resources survey technology of interest to a large number of potential users. Also featured were scientific and technological exploration and research investigations with potential promising applications.

The opening day plenary session was devoted to papers of general interest and an overview. The following 2-1/2 days were devoted to concurrent discipline-oriented technical sessions and to three special sessions covering State and Local Users, Coastal Zone Management, and User Services. These special sessions were structured to provide governmental and private organizations with a comprehensive picture of various applications in the management and implementation of remote-sensing data use in their own programs. The concluding day was a summary with selected state, international, and technical session papers, summaries of significant results from special and technical sessions, and an overview of federal agency and international activities and planning.

Volumes I-A, I-B, I-C, and I-D contain the technical papers presented during the concurrent sessions. Volume II contains the opening day plenary session, special sessions, and the concluding day summary session. Volume III contains a summary of each session by the chairman and session personnel and provides an overview of the significant applications that have been developed from the use of remote-sensing data. Volume III also includes the conclusions and needs identified during the individual sessions and workshops.

Opinions and recommendations expressed in these reports are those of the session members and do not necessarily reflect the official position of NASA.

Olav Smistad
Symposium Coordinator

NASA Earth Resources Survey Symposium

PROGRAM COMMITTEE

Charles W. Mathews, NASA, Chairman
Joseph Ca lson, Public Technology, Inc.
Dr. John DeNoyer, U.S. Geological Survey
Dr. M. Frank Hersman, National Science Foundation
Daniel J. Fink, AIAA, Space Applications Board (NRC)
Harold Finger, General Electric Co.
Dr. Stanley Freden, NASA
Willis Hawkins, Lockheed Aircraft Corp.
Russell R. Schweickart, NASA
Pitt Thome, NASA

SYMPOSIUM COORDINATORS

JOHNSON SPACE CENTER
Olav Smistad
Edward O. Zeitler
Earth Resources Program Office
OFFICE OF APPLICATIONS
Dan Richard, User Affairs

ADMINISTRATIVE SUPPORT

Industrial Economics Research Division
Texas A. & M. University

PRECEDING PAGE BLANK NOT FILMED

SESSION LEADERS

AGRICULTURE
(Includes Agriculture, Forestry, Range Resource Inventory and Management)

Richard Baldwin, Chairman
Cargill, Inc., Minneapolis, Minn.
James Murphy
U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, Houston, Tex.
Ryborn Kirby
NASA Lyndon B. Johnson Space Center, Houston, Tex.
Kenneth Suit
NASA Lyndon B. Johnson Space Center, Houston, Tex.

ENVIRONMENT
(Environmental Surveys and Applications)

Kessler Cannon and Ronald Myles, Chairmen
Department of Environmental Quality, State of Oregon, Portland, Oreg.
Dr. Ralph Shay
Oregon State University, Corvallis, Oreg.
Dr. Lawrence Greenwood
NASA Langley Research Center, Hampton, Va.
Howard Curfman
NASA Langley Research Center, Hampton, Va.

GEOLOGY
(Includes Geological Structure, Landform Surveys, Energy and Extractive Resources)

Dr. Floyd Sabins, Chairman
Chevron Oil Field Research Co., La Habra, Calif.
Dr. Larry Rowan
U.S. Department of the Interior, U.S. Geological Survey, Reston, Va.
Dr. Nicholas Short
NASA Goddard Space Flight Center, Greenbelt, Md.
Robert Stewart
NASA Lyndon B. Johnson Space Center, Houston, Tex.

INFORMATION
(Information Systems and Services)
USER SERVICES

Dr. David Landgrebe, Chairman
Purdue University/Laboratory for Applications of Remote Sensing, West Lafayette, Ind.
Terry Phillips
Purdue University/Laboratory for Applications of Remote Sensing, West Lafayette, Ind.
Timothy White
NASA Lyndon B. Johnson Space Center, Houston, Tex.
Gerald Kenney
NASA Lyndon B. Johnson Space Center, Houston, Tex.

LAND USE
(Includes Regional Planning)
STATE/LOCAL

Charles Parrish, III, Chairman
Department of Natural Resources, State of Georgia, Atlanta, Ga.
Charles Meyers
U.S. Department of Interior, Office of Land Use and Water Planning, Washington, D.C.
Dr. Armond Joyce
NASA Lyndon B. Johnson Space Center, Earth Resources Laboratory, Bay St. Louis, Miss.
Robin Rowley
NASA Lyndon B. Johnson Space Center, Houston, Tex.

MARINE RESOURCES
(Includes Marine Resources, Ocean Surveys)
COASTAL ZONE MANAGEMENT

Senator A. R. (Babe) Schwartz, Chairman
Texas State Senator, Galveston, Tex.
John Sherman, III
National Oceanic and Atmospheric Administration, National Environmental Satellite Service – SPOC Group, Washington, D.C.
E. Lee Tilton, III
NASA Lyndon B. Johnson Space Center, Earth Resources Laboratory, Bay St. Louis, Miss.
William Stephenson
NASA Lyndon B. Johnson Space Center, Houston, Tex.

WATER RESOURCES
(Water Resources Management)

Dr. Daryl Simons, Chairman
Colorado State University, Fort Collins, Colo.
John Teerink
Bookman Edmonston, Inc., Sacramento, Calif.
Dr. Vincent Salomonson
NASA Goddard Space Flight Center, Greenbelt, Md.
Raymond Clemence
NASA Lyndon B. Johnson Space Center, Houston, Tex.

CONTENTS

VOLUME I-B

Geology

Paper number		Page

Paper number | | Page

VOLUME I-C

Land Use

Paper
number | Page

VOLUME I-D

Water

ESTIMATING VEGETATIVE BIOMASS FROM LANDSAT-1 IMAGERY FOR RANGE MANAGEMENT.

Paul M. Seevers, James V. Drew and Marvin P. Carlson, Conservation and Survey Division and Graduate College, University of Nebraska, Lincoln, Nebraska, 68508.

ABSTRACT

Evaluation of LANDSAT-1, b-nd 5 data for use in estimation of vegetative biomass for range management decisions was carried out for five selected range sites in the Sandhills region of Nebraska. Analysis of sets of optical density-vegetative biomass data indicated that comparisons of biomass estimation could be made within one frame but not between frames without correction factors. There was high correlation among sites within sets of radiance value-vegetative biomass data and also between sets, indicating comparisons of biomass could be made within and between frames. Landsat-1 data are shown to be a viable alternative to currently used methods of determining vegetative biomass production and stocking rate recommendations for Sandhills rangeland.

INTRODUCTION

Estimates of vegetative biomass from reflectance data acquired by aircraft and satellites have been evaluated by a number of investigators. In general, these studies indicate that estimates of vegetation density based on reflectance data are complicated by factors associated with the vegetation itself, and with the underlying soil when vegetation does not cover the soil surface completely.

Reflectance is influenced by the kind as well as the density of vegetation. Thus, differences in reflectance were used by Laver and Krumpe (1) to distinguish stands of woody species and herbaceous species, and by Tueller, et al., (2) to distinguish the various vegetation types in Nevada. We have observed that pure stands of different grass species may be differentiated on high-altitude color-infrared photography. Wiegand (3) demonstrated relationships between reflectance measured in multispectral scanner (MSS) bands of LANDSAT-1 and vegetation density in given stands of known crops. In the case of mixed rangeland vegetation, however, estimates of vegetative biomass may be complicated by differences in plant species as well as vegetation density.

A further complexity in estimating vegetative biomass involves the multiple layers of vegetation described by Pearson and Miller (4). The masking of a short-grass layer by a mid- or tall-grass layer is a possibility in mixed-species rangeland. In addition, the presence of continuous vegetative cover can make layering a more critical factor than in areas where vegetation is less dense.

In areas where vegetation cover is discontinuous, however, reflectance characteristics of the soil surface may be a complicating factor in estimating vegetative biomass. For example, it has been shown re-

peatedly that reflectance from a soil surface is influenced by the moisture content of the surface. Moreover, Mathews et al. (5) found that the reflectance from surface soil is also influenced by the amount of clay, silt and organic matter in the soil.

The purpose of this paper is to discuss the use of MSS data acquired by LANDSAT-1 in estimating vegetative biomass in the Sandhills rangeland of Nebraska, and to show the relationship of these estimates to range management decisions.

Study Area

The Sandhills region of Nebraska encompasses about 52,000 square kilometers (20,000 square miles) of rangeland. Certain characteristics of the region tend to minimize potential complexities in estimating vegetative biomass from reflectance data acquired by Landsat-1.

The region is dominated by dunes and intervening valleys composed of eolian sand and stabilized by grasses and grass-like plants. Soils formed in the wind-sorted sands are relatively uniform and contain more than 85 percent sand over approximately 85 percent of the region. Locally, soils containing 50 to 85 percent sand occur in valleys and are often characterized by near-surface water tables and continuous vegetation in response to subirrigation.

Because of the rapid infiltration and permeability of the sandy soils, the soil surface is normally dry in a matter of hours following rain showers, even in subirrigated valleys where the water table is within the lower portion of the soil profile. Thus, the possibility of wet surface soil as a factor influencing reflectance is minimized.

Very few plant species are unique to specific soils or range sites within the Sandhills region, except in wetland areas where relatively pure stands of water-tolerant species occur. Although the native vegetation consists of a mixture of species including short- and midgrasses, the distribution and density of rangeland plants is such that reflectance is not generally influenced by multiple layers of vegetation.

Vegetation surveys indicate a relatively high constancy (percentage of sites on which a given species is found) for the major forage-producing species. Woody plants are relatively insignificant within the native vegetation. Consequently, the relative non-segregation of species minimizes the influence of species differences on reflectance values.

Methods

Five selected range sites were sampled during the fall of 1972 and from May through October of 1973 and 1974. Vegetation within a quadrat one square meter in size at each site was clipped within three days of selected overpasses of LANDSAT-1. Dry weights of the samples as well as field observations related to range condition were obtained for each site.

Imagery from MSS band 5 acquired by Landsat-1 for the test sites was evaluated by optical density measurements of 1:1,000,000 positive transparencies using a McBeth densitometer. Readings represented average optical densities for ground areas of approximately 60 hectares (150 acres), well within the boundaries of the (600-1000 acre) 240-400 hectare management units studied. Correlation coefficients were then calculated for the resulting sets of optical density-vegetative biomass data.

In addition, printouts from computer compatible tapes of radiance values for MSS band 5 were used to obtain an average radiance value for an area 9 to 18 hectares (22 to 44 acres) in size at each test site. Averages of 20 to 40 picture elements were determined for each site. These average radiance values were then used to calculate correlation coefficients for the resulting sets of radiance value-vegetative biomass data.

Results

Vegation on the five sites consisted of mixtures of short- and mid-grasses, although the mid-grasses tended to increase as range condition improved. Several species were common to all sites: Calomovilfa longifolia (prairie sandreed), Sporobolus cryptandrus (sand dropseed), Boutelova gracilis (blue gramma), Koeleria cristata (prairie junegrass), and Carex species. Poa compressa (Canada bluegrass) was found on only two of the sites, while Muhlenbergia pungens (sandhills muhley) was found only on one site. Live vegetation constituted from 11 to 39 percent of the plant cover on the five sites.

The high correlation coefficients obtained for the sets of radiance value-vegetative biomass data from the five test sites indicated that reliable estimates of vegetative biomass can be made from MSS band 5 data obtained within the Sandhills region. However, greater variation existed among correlation coefficients for sets of optical density-vegetative biomass data than among corresponding sets of radiance value-vegetative biomass data.

Table 1 shows a relatively wide range of correlation coefficients from .20 to .94 for the sets of optical density-vegetative biomass data. A composite analysis of these 1973 data sets resulted in a low negative correlation coefficient (-.20). In contrast, Table 2 shows relatively high correlation coefficients ranging from -.79 to -.93 for the sets of radiance value-vegetative biomass data. In addition, the correlation coefficient for a composite analysis of the 1972-1974 data was high (-.85).

Discussion

Statistically, the data in Table 2 indicate high reliability for remotely sensed estimates of vegetative biomass in the Sandhills region using radiance values in band 5 from computer compatible tapes. The close relationships obtained for the sets of radiance value-vegetative biomass data in comparison with the sets of optical density-vegetative biomass data probably result from the smaller and more uniform ground

areas measured for radiance values as opposed to the larger and less uniform ground areas measured for optical density.

In addition, the relatively high correlation coefficient for the composite analysis of the sets of radiance value-vegetative biomass data (-.85) suggest that valid comparisons can be made of radiance values obtained on different dates by LANDSAT-1. Correlation coefficients for the sets of optical density-vegetative biomass data indicate that comparisons of optical densities within a LANDSAT frame are valid, but the low correlation coefficient for the composite analysis of these data suggests that valid comparisons of optical density on frames acquired on different dates cannot be made without application of correction factors.

Other investigators have utilized ratios of radiance values, usually between band 5 and band 6 or 7, to estimate vegetation density or biomass (3, 6). These ratios correlate with "green" biomass and are influenced by near-infrared reflectance in band 6 or 7 from vigorous, healthy, green plants as well as visible red reflectance in band 5. In the Sandhills rangeland, however, moisture stress may reduce near-infrared reflectance from the vegetation and thus indicate a decrease in vegetative biomass. Nevertheless, range plants under moisture stress are legitimate sources of forage, and vegetative biomass does not necessarily decrease during periods of moisture stress. Our results indicate that estimates of vegetative biomass in the Sandhills region using radiance values in band 5 alone involve a balance between the absorption of visible red light by live plant tissue and the reflectance of visible red light by exposed sandy soil.

Since range management involving animal stocking rates is based on the forage producing capability of individual management units, estimates of vegetative biomass within management units are important for management decisions. Two sites were selected from the five sites studied in the Sandhills region to illustrate management practices and to show management decisions based on traditional field estimates of forage production in comparison with satellite estimates of vegetative biomass.

One of these sites (Site A) was not grazed or mowed during the growing season of 1973. This permitted direct measurement of the maximum production of vegetative biomass. Clipping data obtained from Site A at intervals during the growing season showed a typical curve for forage production (Figure 1).

A second site (Site B) was subjected to grazing by livestock during the growing season so that a portion of the vegetative biomass was removed from the site. Thus, maximum production of forage could not be measured at Site B, but was judged on the basis of maximum potential production and an estimate of vegetative biomass removed by grazing animals. The decline in vegetative biomass at Site B after June 18, 1973, with the exception of small increases in response to periodic rain showers, showed the influence of grazing in removing vegetative biomass (Figure 1).

Data obtained at Sites A and B were compared with range management decisions based on field criteria developed by the Soil Conservation Service (SCS, USDA) through extensive experience within the Sandhills region. Site A showed good agreement between vegetative biomass measured by clipping and the recommended stocking rate. Clipping data from this site showed a maximum production of 1665 kilograms of vegetative biomass per hectare (1480 lb. per A). Recommended management for this site according to SCS criteria involved the utilization of one-fourth of the maximum production on one acre by one animal unit per month. Thus, 416 kilograms (370 lb.) of vegetative biomass would be utilized from Site A per month under good management.

Assuming that one animal unit requires 848 kilograms (750 lb.) of vegetative biomass per month, each acre of Site A would provide 0.5 animal units per month. This is the actual stocking rate recommended for Site A by the SCS on the basis of field criteria.

In the case of Site B, grazing was permitted on the site during most of the growing season. Thus, it was not possible to estimate actual maximum production either from clipping data or radiance values. Based on an SCS field estimate of "good" range condition class for Site B, however, maximum production should approximate 3390 kilograms per hectare (3000 lb. per A.). Radiance values from band 5 correlated with clipping data indicated approximately 1665 kilograms of vegetative biomass per hectare (1485 lb. per A.) at Site B during the period of peak production on June 18, 1973.

Application of SCS field criteria at Site B indicated "close" grazing on June 18, 1973, suggesting that more than the recommended amount of forage had been removed. Following the recommended management practice of utilizing one-fourth of the maximum production per month, approximately 1013 kilograms (2250 lb.) of vegetative biomass should have remained at Site B on June 18, 1975. Instead, the estimate of vegetative biomass from the radiance values as well as observations in the field indicated that "close" grazing had removed approximately one-half of the vegetative biomass.

Thus, estimates of vegetative biomass from LANDSAT-1 were correlated with clipping data and with SCS range management recommendations based on judgments in the field.

Conclusion

In the past, recommendations for stocking rates have been based on field estimates of species composition and the percent of vegetative cover, the best estimate of climatic conditions for the growing season, and experience. Normally, the agencies involved in recommending management plans do not have the manpower or resources necessary to collect sufficient data on vegetative biomass through clipping studies. Since radiance values acquired by LANDSAT-1 may be interpreted to give reliable estimates of vegetative biomass, these data provide an alternative for making recommendations for stocking rates over large areas. To be of maximum benefit, however, LANDSAT data

must be available to decision makers within seven to ten days after acquisition.

1. Laver, D. T. and P. F. Krumpe. 1973. Testing the usefulness of ERTS-1 imagery for inventorying wildland resources in northern California. Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1, Vol. I--Technical Presentations, Sec. A. NASA SP-327, p. 97-104.

2. Tueller, Paul T., Garwin Lorain and Ronald M. Halvorson. 1973. Natural Resource Inventories and Management Applications in the Great Basin. Third Earth Resources Technology Satellite-1 Symposium. Vol. I, Technical Presentations. NASA SP-351, pp. 267-289.

3. Wiegand, C. L., H. W. Gausman, J. A. Cueller, A. H. Gerbermann and A. J. Richardson. 1973. Vegetation density as deduced from ERTS-1 MSS response. Third Earth Resources Technology Satellite-1 Symposium. Vol. I, Technical Presentations. NASA SP-351, pp. 93-116.

4. Pearson, Robert L. and Lee D. Miller. 1972. Remote mapping of standing crop biomass for estimation of the productivity of the shortgrass prairie, Pawnee National Grasslands, Colorado. Proc. Eighth International Symposium on Remote Sensing of Environment, pp. 1-25.

5. Mathews, H. L., R. L. Cunningham and G. W. Peterson. 1973. Spectral reflectance of selected Pennsylvania soils. Soil Sci. Soc. Amer. Proc. 37:421-424.

6. Rouse, J. W., Jr., R. H. Haas, J. A. Schell and D. W. Deering. 1973. Monitoring Vegetation systems in the great plains with ERTS. Third Earth Resources Technology Satellite-1 Symposium. Vol. I, Technical Presentations NASA SP-351, pp. 309-317.

TABLE I. - COEFFICIENTS OF CORRELATION RELATING OPTICAL DENSITY VALUES OF POSITIVE TRANSPARENCIES FROM LANDSAT-1, BAND 5, TO VEGETATIVE BIOMASS ON FIVE TEST SITES.

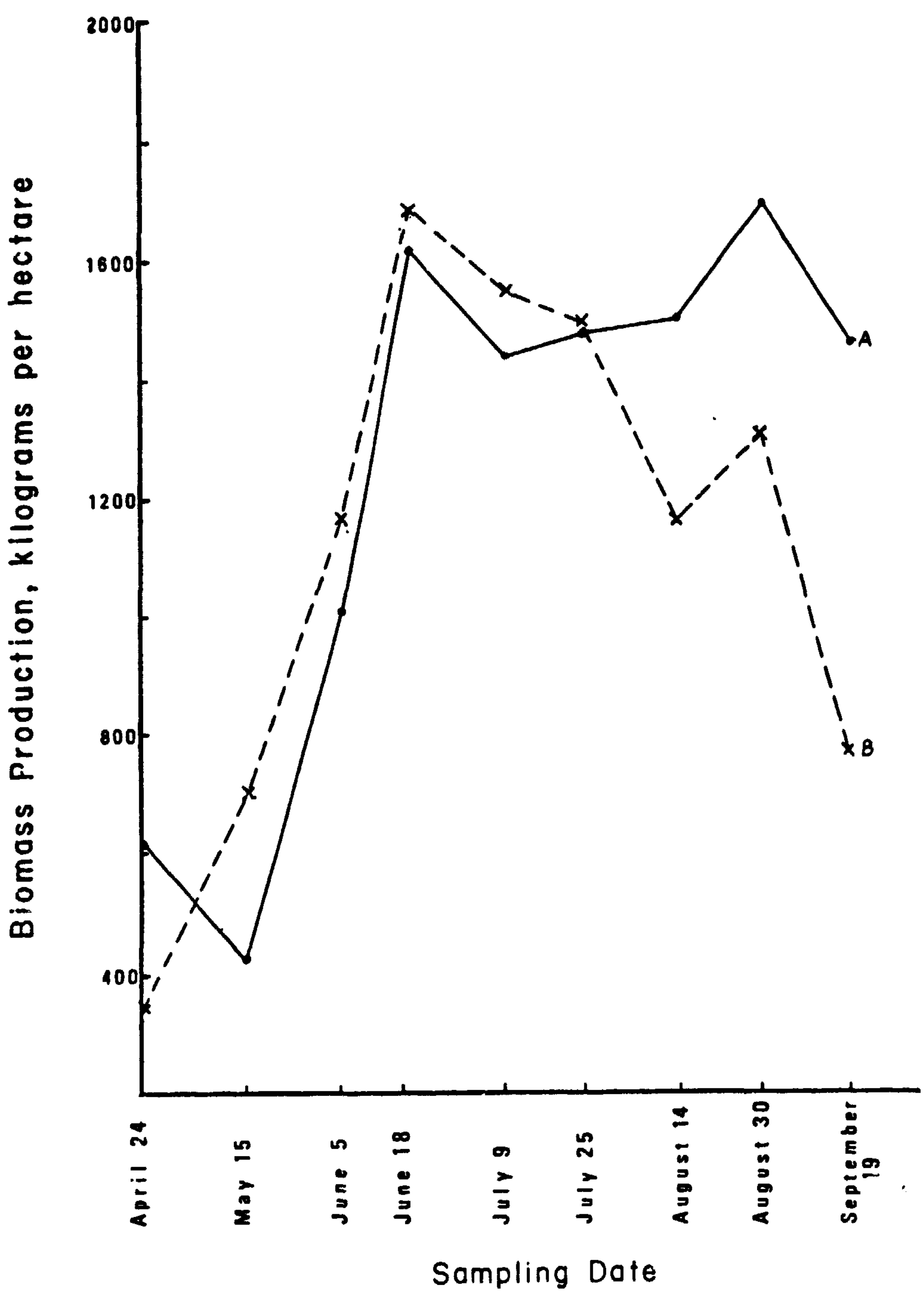
Overpass Date 1973	Vegetative Biomass Range, kg/ha	Optical Density Range	Correlation Coefficient
May 14	134-684	.74-.84	.20
June 1*	540-1167	1.04-1.21	.78
July 26	371-1444	.49-.67	.94
August 17	297-1432	.29-.45	.74
September 22	355-1413	.71-.88	.82

* Four sites only.

TABLE II. - COEFFICIENTS OF CORRELATION RELATING RADIANCE VALUES FROM LANDSAT-1, BAND 5, TO VEGETATIVE BIOMASS ON FIVE TEST SITES.

Overpass Date	Vegetative Biomass Range, kg/ha	Radiance Value Range	Correlation Coefficients
Sept. 4, 1972	825-2396	23.38-36.77	-.93
May 14, 1973	380-684	36.33-45.53	-.92
Aug. 12, 1973	297-1432	26.57-38.83	-.83
July 5, 1974	876-1944	29.48-47.68	-.79

FIGURE I.-VEGETATIVE BIOMASS PRODUCTION ON TWO SITES SHOWING UNGRAZED (SITE A) AND GRAZED (SITE B) PRODUCTION CURVES.



A-2

N76-17471

DISCRIMINATING COASTAL RANGELAND PRODUCTION AND IMPROVEMENTS WITH COMPUTER AIDED TECHNIQUES

C. A. REEVES
D. P. FAULKNER

Lockheed Electronics Co., Inc.
Aerospace Systems Division
Houston, Texas

INTRODUCTION

In preparing for rangeland management, a working concept for rangelands must be realistically broad in definition. The term range implies a land-use dominated by the grazing of domestic animals. In a broader sense, it includes lands with either a potential for or past history of grazing by either native or domestic herbivores.

In this context, range management has been defined as the art and science of planning and directing range-use to obtain sustained maximum animal production, consistent with perpetuation of the natural resources (ref. 1). This definition gives the production of domestic livestock and wildlife a priority status in a developing and expanding discipline while recognizing other potential goods and services that can be provided by rangelands. Scientific range management stands on the premise that vegetation can be used perpetually for grazing while simultaneously providing society with high quality air, water, open space and recreation (ref. 2).

The role of remote sensing in range management is to provide information important to decision-making. This information is inventory-related and can include such parameters as species composition, environmental relationships, range condition and vegetation productivity. Also, the data products are frequently used as base maps to display management plans.

The purpose of this study was to test the feasibility and utility of using satellite data and computer-aided remote sensing analysis techniques to conduct range inventories. Both the inventory levels and accuracies and the analysis techniques were tested.

Coastal rangeland along both Gulf and Atlantic coasts has been largely overlooked in rangeland studies. Although acreage is small compared to other grazing regions, the area is important for animal production. A high potential exists for extensive range improvement practices and corresponding resource information. The study site was chosen to represent rangelands within the Gulf coast portion of the prairie and marshland region.

The Gulf coast region occupies approximately 9,500,000 acres along the Texas coast. The coastal prairie is nearly level, poorly drained plain less than 150 feet above sea level. Frequent rivers, bayous or other streams dissect the area. The marshlands are limited to a narrow belt immediately adjacent to the coast and occasionally projecting inland along the bayous.

Most of the region is grazed by cattle with a few sheep, goats and horses scattered throughout the area. Ranches and rangelands of the prairie uplands are interspersed with farms. The better soils are highly productive under cultivation or as improved pastures. Wildlife, especially deer, is abundant enough throughout the region to be economically important.

The principal climax plants of the prairie are tall bunch grasses such as big bluestem (Andropogon gerardi), seacoast bluestem (A. littoralis), Indiangrass (Sorghastrum nutans), eastern gamagrass (Tripsacum dactyloides), and a gulf muhly (Muhlenbergia capillaris, var. filipes). Much of the area has been invaded by trees and brush such as mesquite (Prosopis juliflora, var. glandulosa), oaks (Quercus spp.), pricklypear (Opuntia, spp.) and several acacias. The marsh areas typically support species of Carex, Cypress, Juncus, Scirpus, several cordgrasses (Spartina), seashore saltgrass (Distichlis spicata), and marsh millet (Zizaniopsis miliacea). Introduced grasses such as bermuda (Cynodon dactylon), dallisgrass (Paspalum dilatatum), and carpetgrass (Axonopus affinis) are common in tame pastures and have become locally established in some native range areas (ref. 3).

The animal carrying capacities of these rangelands are highly variable. The native grasslands historically require 6 to 8 acres to carry one animal unit for a year. Where brush or trees have invaded, this capacity is lowered. Range improvement practices such as brush removal and seeding to improve grasses raises the carrying capacity to 1 acre per animal unit. Even though the marshlands are grazed, they are considered unproductive.

STUDY SITE

An initial rangeland survey was conducted over a 250,000 acre site in Galveston and Brazoria Counties along the Texas Gulf Coast (fig. 1). Features in the study site include intensive agriculture, urban areas, industrial complexes, coastal marshes, and rangelands. Much of the area is covered by water from numerous bays, inlets, and bayous. The coastal marshes normally have a high vegetative cover (over the shallow water) but may be completely inundated after heavy rains or tidal winds. The rangelands consist of improved pastures, native grasslands, and the coastal marshlands.

GROUND BASE

Rectifi· . : 'arged aircraft color infrared photographs (1:24,000), film type Kodak 2443, o .is site (Mission 208, August 30, 1972) were used as the ground truth base. The different land categories were identified, delineated and measured. These photographs were used both to help select training areas and as a standard to test classification accuracy.

COMPUTER-AIDED CLASSIFICATION

In the analysis, multispectral scanner (MSS) bulk data from the LANDSAT-1 pass of August 29, 1972 (ID 1037-16251) over the Texas Gulf Coast was obtained from the Goddard Space Flight Center (GSFC). During the preprocessing procedure, the entire scene was screened and edited to select the 101,175 hectares (250,000 acres) intensive study site.

The digital data processing flow is diagrammed in fig. 2. The pattern recognition system used in this study was the Image 100 System, a multispectral image processing and analysis system. This system utilizes a PDP-11 series computer with standard "peripherals" (image analyzer console, line printer, graphic display terminal, magnetic tape drives, input scanner unit, solid state refresh memory) (fig. 3). Computer printout, cathode ray tube (CRT), and film positive options were available for display of classification results. At present, four channels of eight bit MSS data can be input. The console screen displays 512 by 512 picture elements.

Using an adjustable electronic cursor, the analyst spacially defines training areas that depict a feature. The areas classified as a feature are both visually displayed on the screen and tabulated as pixels per feature. The classification results can be output as a grey scale printout or as a digital tape (ref. 4).

CLASSIFICATION RESULTS

An intensive study area of approximately 250,000 acres was selected incorporating parts of Galveston and Brazoria counties along the Texas Gulf Coast.

Features of interest were delineated on the image console giving the number of picture elements classified (fig. 4). The picture elements (pixels) were converted to acreages. The results are shown in the following table.

Water	52611 hectares (130,000 acres)
Marsh	4452 hectares (11,000 acres)
Range	21044 hectares (52,000 acres)

The remaining 23068 hectares (57,000 acres) in the scene (urban, cropland, industrial and transportation networks) were unclassified.

To evaluate the accuracy, three intensive test sites were selected within the marshes. Site 1 is a large marsh surrounded on the west by range and on the east by Galveston Bay. Site 2 is a marsh surrounded by other types of vegetation. Site 3 is marsh surrounded on the west by Swan Lake and on the east by Galveston Bay (fig. 4). Each area was classified and pixels per feature determined. The classification results were then compared to the aerial photo statistics as a measure of classification accuracy. Results were tabulated in the following table:

Feature	Classified	Ground Truth	Accuracy
Site 1	323 hectares (822 acres)	350 hectares (866 acres)	95.5%
Site 2	83 hectares (207 acres)	191 hectares (191.3 acres)	92.3%
Site 3	68 hectares (169 acres)	149 hectares (149.6 acres)	88.8%

Accuracies for computer aided classification of coastal marshes range from 89% to 96%.

SUMMARY

This study has successfully demonstrated that broad rangeland types can be accurately separated to acceptable levels on LANDSAT bulk data with a computer aided classification

procedure. Although this was a pilot study, the output classification could be used by land managers as an input to their rangeland inventory. It is important that area range managers be able to separate the range types that were classified in this study. The marshes have very low productivity for livestock but are important as wildlife habitat. The native rangelands conversely are very productive and potentially can be made even better under more intensive management.

It was also determined that this first step just "scratched the surface" in extracting inventory information. A second step to further refine the classification is needed to differentiate improved pastures from the native rangelands.

A third step would be to monitor changes as native rangelands are converted to improved pastures and as climatic or seasonal aspects influence these lands.

These steps are necessary for the development of a dynamic model based on inputs from remotely sensed data, and to predict variations in carrying capacity of rangelands as affected by seasonal variations and range improvement practices. This model could take advantage of the unique multispectral and repeat coverage characteristics of the LANDSAT type satellites. The products of this model have the potential of aiding the range manager to become a more efficient and more accurate decision maker and at lower cost.

REFERENCES

1. ASRM Range Term Glossary Committee: A glossary of terms used in range management. Society for Ranoe Management, Denver, Colorado, 32pp., 1964.

2. AHON: Range Ecosystem Research - The Challenge of Change. USDA, U. S. Forest Service, USDA Agricultural Information Bulletin 346, Washington, D.C.

3. Gould, F.W.: Texas Plants -- A Check List and Ecological Summary. Texas Agric. Exp. Station, Texas A&M University, College Station, Texas. 121pp., 1969.

4. ANON: System Description Image 100 Interactive Multispectral Spectral Image Analysis System Description. General Electric Co., Daytona Beach, Fla. Doc. No. 717 001SD, March, 1975.

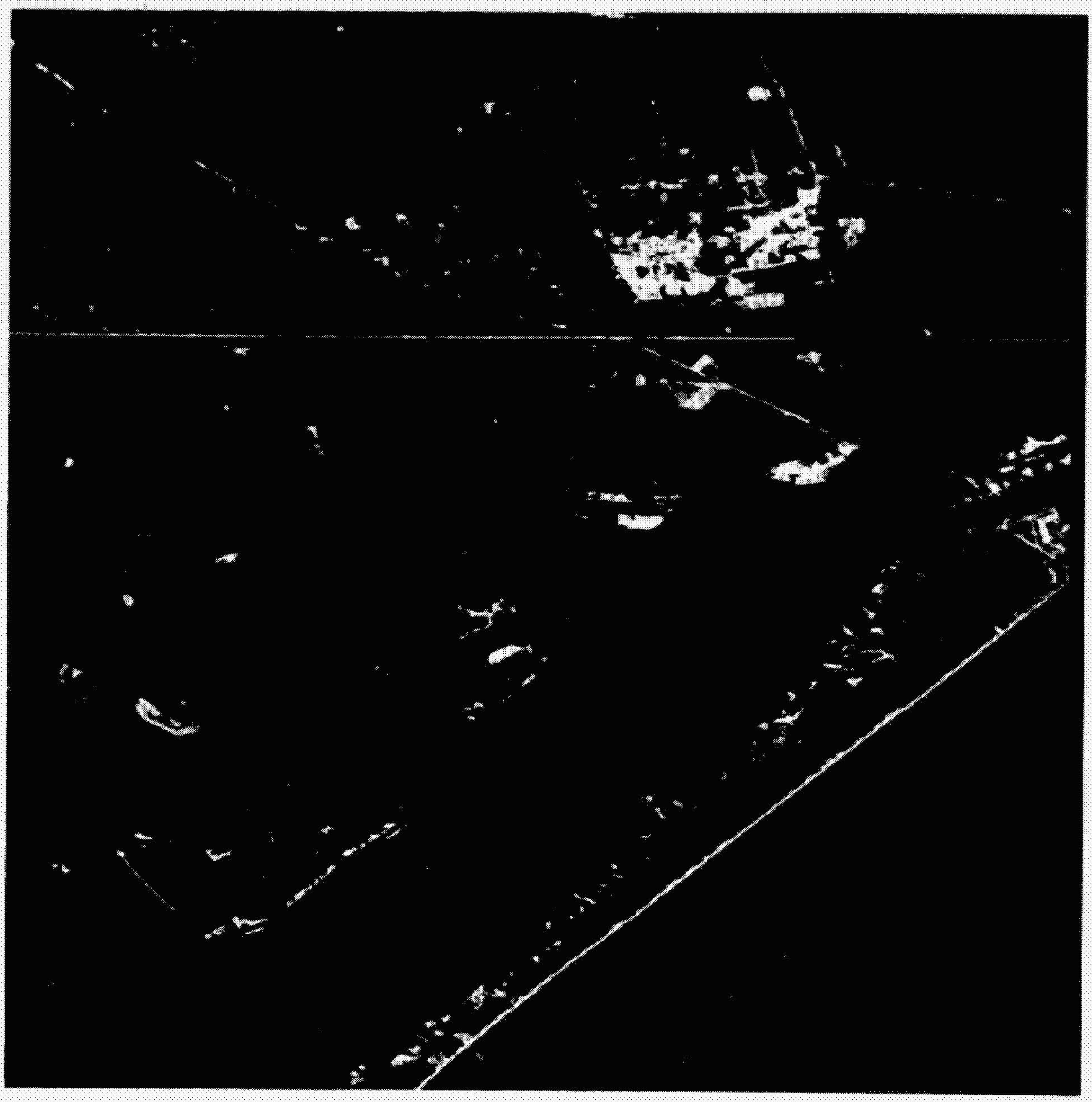


FIGURE 1 LANDSAT-1 IMAGERY AUGUST 29, 1972
(ID 1037-16251) OF STUDY SITE

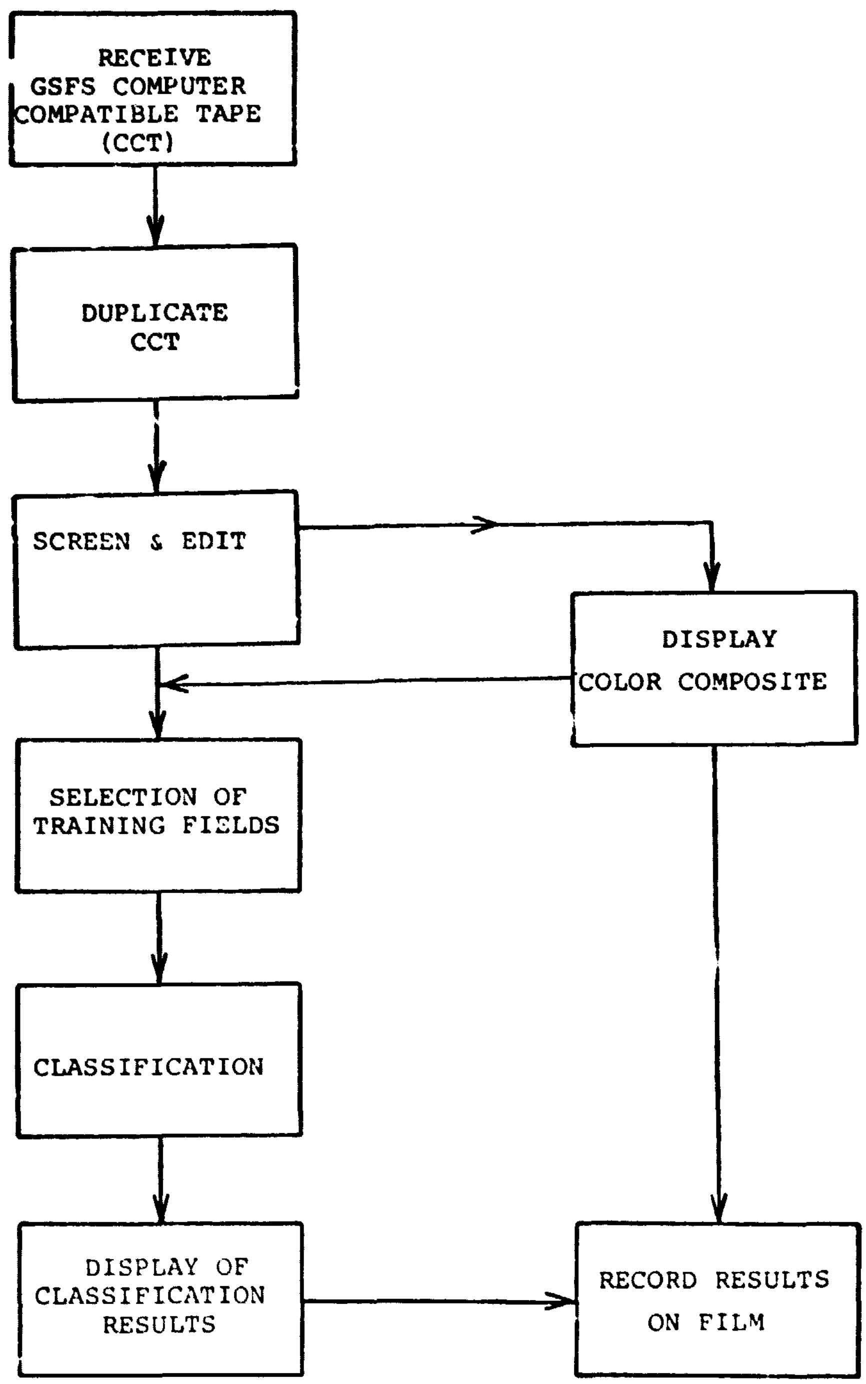


FIGURE 2 DIGITAL DATA FLOW DIAGRAM

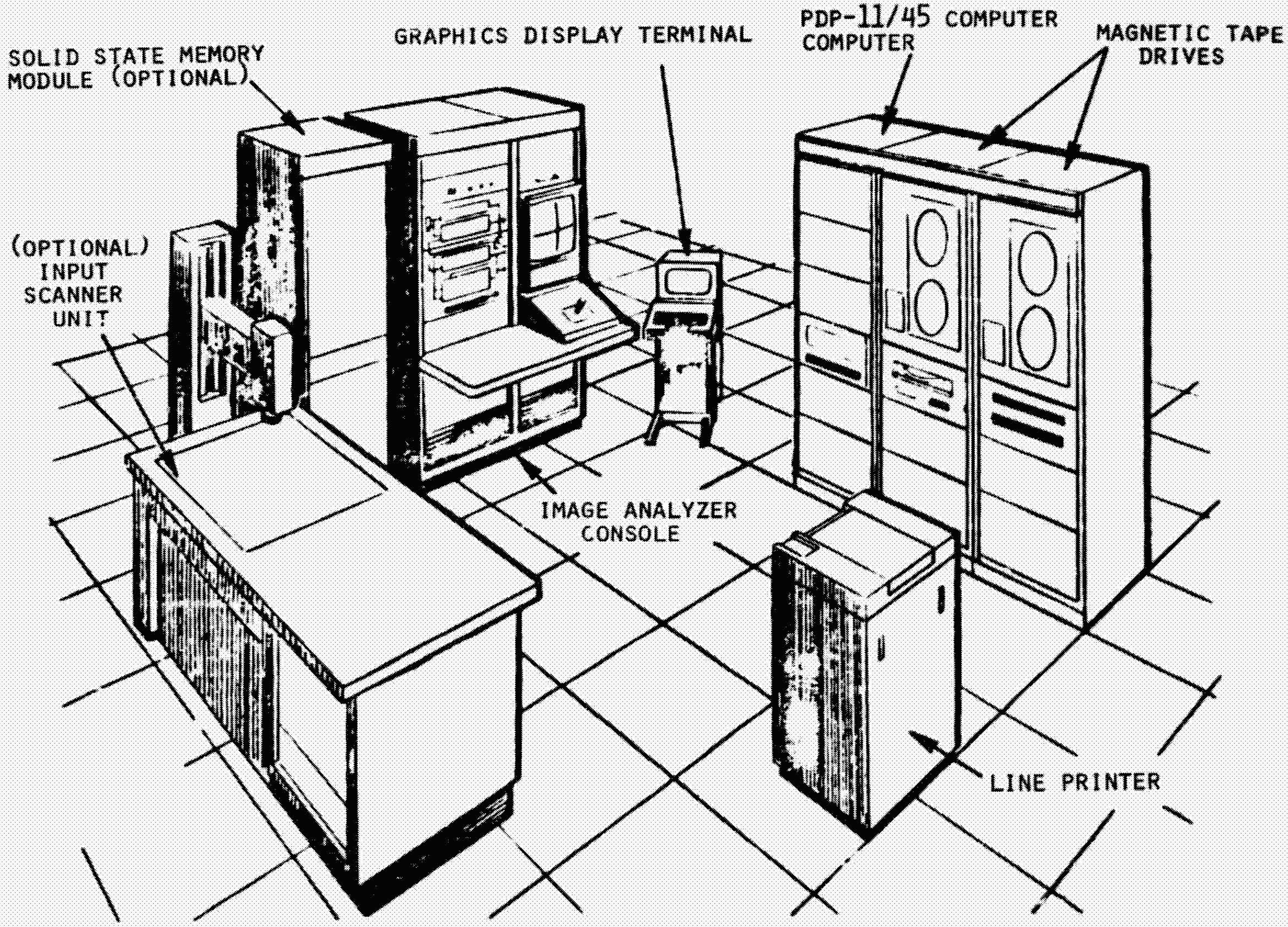


Figure 3. — Image 100 System.

FIGURE 4 - CLASSIFICATION MAP OF STUDY SITE, GREEN-RANGE, BLUE-WATER
SALMON-MARSH, RED AND WHITE - OTHER.

USEFULNESS OF LANDSAT DATA FOR MONITORING PLANT DEVELOPMENT AND RANGE CONDITIONS IN CALIFORNIA'S ANNUAL GRASSLAND

A-3

By David M. Carneggie, EROS Data Center, Sioux Falls, South Dakota,
Stephen D. DeGloria, University of California, Berkeley, and
Robert N. Colwell, University of California, Berkeley, California

ABSTRACT

N76-17472

The California annual grasslands are economically important rangelands. They do, however, present some problems to livestock producers due to the shortlived nature of the forage. Livestock production can be maximized on these lands if the ranchers can receive a better idea of when, how much, and how long forage will be available.

The investigators established a network of sampling sites throughout the annual grassland region to correlate plant growth stages and forage production to climatic and other environmental factors. Plant growth and range conditions were further related to geographic location and seasonal variations.

A sequence of LANDSAT data was obtained covering critical periods in the growth cycle. This data was then analyzed by both photointerpretation and computer aided techniques. Image characteristics and spectral reflectance data were then related to forage production, range condition, range site and changing growth conditions.

As a result of this study, it was determined that repeat sequences with LANDSAT color composite images do provide a means for monitoring changes in range condition. LANDSAT spectral radiance data obtained from magnetic tape can be used to determine quantitatively the critical stages in the forage growth cycle. In addition, a computer ratioing technique provided a sensitive indicator of changes in growth stages and an indication of the relative differences in forage production between range sites.

The anticipated benefits from LANDSAT monitoring of annual range vegetation include: (1) more accurate determination of germination and drying periods for planning movement of grazing animals to or from annual grassland ranges; (2) predictions of the remaining length of the green feed period made early enough to plan more efficiently for alternative sources of livestock feed; (3) comparison of conditions and relative forage production between grazing areas within a season; and comparison of condition and productivity for a given area between seasons; (4) determination of time when dry forage creates a fire hazard in order to better allocate men and equipment for fire suppression; and (5) assess extent and location of grazing areas influenced by abnormal climatic conditions, be it drought or abundance of forage.

PRECEDING PAGE BLANK NOT FILMED

INTRODUCTION

NASA's Earth Resources Technology Satellite (LANDSAT-1) launched July 23, 1972, provided an unique capability for regional monitoring of forage plant development within rangeland environments. The repetitive coverage, the synoptic view and the opportunity for acquiring real time imagery combine to make LANDSAT data a valuable input for determining seasonal range conditions, and forage production. A LANDSAT investigation for the Bureau of Land Management (United States Department of Interior) conducted at the University of California, Berkeley, examined the feasibility of using LANDSAT data to: (a) monitor growth and development of forage plants in the Annual Grassland in California; (b) determine the relative amount of forage produced within and between growth seasons for a given area; (c) map grasslands with different forage production, and (d) predict forage condition and production using models which incorporate ground forage samples, spectroradiometric and climatic data. The study was conducted primarily during the 1972-73 growth cycle, with subsequent comparison of LANDSAT data during the 1974-75 growth cycle. The study area includes the annual grassland range seen within the LANDSAT images of San Francisco Bay; however, observations and measurements of plant growth and spectral data were made at two test sites; Pinole, located within a 50cm rainfall zone, 10 miles northeast of Berkeley, and San Luis Reservoir, located within a 25cm rainfall zone along the shore north of San Luis Reservoir located about 10 miles west of Los Banos, California.

California Annual Grassland

The annual rangeland in California is located primarily in the foothills of the Coast Range and Sierra Nevada Mountains. They are economically important by virtue of the area they occupy (8 to 10 million hectares) and the amount of forage they produce. These ranges are characterized by a complete cover of grasses, clovers, and forbs, which germinate in the autumn following a sufficient amount of rainfall to adequately wet the soil. Foliage growth is generally slow through the winter, followed by accelerated growth during the late winter and early spring. Plants mature, flower and subsequently dry during the spring in response to depletion of soil moisture.

Within the annual grassland range there are various grazing regions which differ in physiography, geomorphology and climatic regime. As a result they also differ in species composition, rate and timing of plant development, season of use by grazing animals, plant density, structure and productivity. (Talbot, Biswell, Hormay, 1939; Biswell, 1956; Heady, 1958). Because of seasonal variations in weather patterns within and between the different grazing regions, the condition and production of forage are also variable (Heady, 1958). The lowest forage producing areas are in the low rainfall zones (13-15 cm) in the southern portion of the annual grassland range, whereas the highest producing areas are in central California (50-75cm rainfall zone). Forage production in the northern portion of the annual grassland range is generally 30% less than the central portion due to lower temperatures despite the higher amounts of rainfall it receives (100-125cm) (Janes, 1969).

Within any given grazing region forage production and the length of the green growth period vary from year to year depending upon the climate pattern. Production also varies from site to site depending upon elevation, slope, aspect, the climatic regime, and various physical, chemical, and biological characteristics of the soil. Generally, sites with northeast exposure remain green longer and have higher forage production compared to sites on a southwest exposure. Similarly, sites with deep, fine textured soils, having high water holding capacities, remain green longer and have higher forage production than sites with

shallow, coarse textured soils. Plant species which occur more frequently on the productive sites include: wild oats (Avena fatua, A. barbata); soft chess (Bromus mollis); ripgut brome (Bromus rigidus); wild barley (Hordeum); Italian ryegrass (Lolium multiflorum); bur clover (Medicago hispida). Forage species commonly associated with less productive range sites include: foxtail fescue (Festuca megalura); red brome (Bromus rubens); filaree (Erodium botrys, E. cicutarium); clovers (e.g. Trifolium microcephalum); wild barley (Hordeum), annual forbs; bur clover (Medicago hispida).

Cattle and sheep are the primary grazers of annual rangeland. Approximately 50 to 80 percent of the 5.2 million cattle and 1.1 million sheep in the state spend a portion of their lives on the annual range. Grazing occurs primarily during the winter and spring months, but some livestock operators retain their animals on the dry annual rangelands throughout the summer. Generally, however, once the forage has been depleted or dried, resulting in lower nutritive quality, (Hart, Guilbert, and Goss, 1932) the animals are moved from the range to green pastures in the Central Valley, to feedlots or to perennial summer ranges.

Range Conditions During the 1972-73 Growth Period

The first rains of the 1972-73 season fell in late September causing germination of the annual forage throughout the northern half of the state. The second rains occurred in mid-October causing further germination to the south over approximately half of the remaining range where germination had not occurred. Finally, rains during the first and second weeks of November caused germination throughout the remaining annual grassland areas. This southward progression of germination was monitored by the LANDSAT passes in October and November. By April, the forage in the lower rainfall belts had reached maturity and had begun to dry. Drying occurred first along the east side of the Coast Range and gradually progressed northward and to higher elevations during May. By the end of May most of the annual forage in the state was dry. LANDSAT imagery obtained during this time period made it possible to monitor the location and progression of drying throughout many sites in the California annual rangeland. (Carneggie & DeGloria, 1973.)

METHODS

Collection of Ground Data

A network of sampling sites was established throughout the state from regions representing different climatic regimes. Two of the sites were the Pinole and San Luis Reservoir Test Site seen with the LANDSAT image of San Francisco Bay. Measurements and observations of the annual plants were collected between October 1972 and June 1973. At each site observations of phenological stage, for example, the time periods when germination, maturity and drying occurred, were recorded. Ground photographs were taken periodically at each sample site to provide a permanent record of the phenological stage of plant growth, and the relative condition (greenness or dryness) of the plants.

At each test site two or three replicate samples of plant weight, height, and spectral reflectance were obtained periodically from grazed and ungrazed plots located on several different sites. Plant weight estimates were obtained by clipping the forage to ground level within a one square-foot quadrat. The dry residual material from the previous season was removed and the current growth was oven dried and weighed. Plant height measurements were the average length of the forage or inflorescences within the sample plots. Graphs of forage production at grazed and ungrazed plots at Pinole and San Luis Reservoir appear in Figure 1. These graphs show the differences between sites located in different rainfall zones in terms of date of germination, amount of forage produced under moderate grazing

and without grazing, and the time when production ceased, which generally coincided with the drying period.

Ground spectral reflectance measurements were obtained at the Pinole Test Site throughout the growing period; however, spectral readings were made only during the rapid growth period at other sites. Spectral readings were corrected for sensitivity throughout the spectrum from 400nm to 1200nm. Corrections were not made for sun angle, season of the year or time of day because the primary use of the data was to form spectral reflectance ratios which were compared for the different dates of measurement. Generally the spectral reflectance readings were made just prior to the removal of a forage sample and close to highest sun zenith. The reflectance ratios were formed by dividing reflectance readings in the near infrared (800nm) by the reflectance readings in the red (675nm). This ratio has been shown to be highly correlated with green biomass (oven dried) in the short grass prairie region (Tucker, Miller, and Pearson, 1973); thus, similar studies were performed in the California annual grassland to test its applicability. Roberts and Gialdini (1973) have shown that infrared reflectance decreased while reflectance in the red band increases as annual forage matures and dries, corresponding to a declining amount of green biomass. Ratios formed by reflectance in the infrared and red bands would decrease with declining amounts of green biomass. Other LANDSAT investigators have also shown correlations between green plant biomass and LANDSAT reflectance data in bands 7 and 5 (Rouse, J. W. et.al, 1973; Maxwell and Johnson, 1974). Figure 2 shows the ground spectral reflectance ratio curves, green forage production curves (oven dried), and phenological data at the Pinole Range Test Site.

LANDSAT Imagery Analysis

Cloud-free LANDSAT-1 imagery of the San Francisco Bay Area was available on October 6, October 24, 1972, and January 4, January 22, April 4, April 22, May 10, May 28, and June 15, 1973. This imagery provided the opportunity to observe the initiation of germination, the peak of the growth period, and the progression of maturity and drying. LANDSAT-2 imagery taken over the same area in January 1975, provided an opportunity to compare seasonal development between growing seasons.

Nearly all of the cloud-free LANDSAT imagery which provided coverage of the ground sampling sites was processed to color composites simulating color-infrared images. Color Plate I shows a sequence of LANDSAT color composites of the test site located in Pinole Valley, east of Berkeley. The accompanying ground photographs (Color Plate II) were taken at approximately the same time as the LANDSAT images and document the changes in appearance and condition of the forage during the 1972-73 growth period. Hand held vertical ground photographs were also taken over each sample site to provide a pictorial record of the stage of plant development corresponding to the various dates of LANDSAT overpasses. The ground photographs along with the written record of phenological stage provided the ground references used to evaluate the changing appearance of the annuals as viewed on the LANDSAT color composites. The LANDSAT images provide a reference base for recording and interpreting range condition throughout a large region, and for making comparisons of range conditions in previous or subsequent years. The opportunity provided by LANDSAT imagery to accurately and unbiasedly compare range conditions between grazing regions in any given year, and to compare conditions for a given site between years, is fundamental to the development of an operational range monitoring system.

LANDSAT Data Tape Analysis

LANDSAT tapes for all cloud-free passes over the San Francisco Bay Area, which contain the Pinole and San Luis Reservoir Test Sites, were acquired in order to analyze the spectral data in each of the four spectral bands (4, green; 5, red; 6, near-infrared; 7, near infrared). The objectives for analyses were (1) to determine if LANDSAT spectral data provide

a reliable means for assessing forage conditions, and (2) to examine the relationship between LANDSAT spectral data, ground spectral data, phenology and forage production curves. The LANDSAT tapes analyzed included: July 26, 1972, August 13, 1972; October 6, 1972; January 4, 1973; April 4, 1973; April 22, 1973; May 10, 1973, and May 28, 1973. On each of the magetic tapes, the spectral radiance values associated with two areas measuring 6 x 6 picture elements in size, (which corresponded with the Pinole and the San Luis Reservoir Test Sites) respectively, were analyzed. No corrections were made for atmospheric variables; however, each date of imagery analyzed was a relatively clear day without any apparent clouds. The average and standard deviation were computed for both areas for each date, and for each MSS band. Figures 3 and 4 show the graphs of LANDSAT spectral radiance plotted over time for the Pinole and San Luis Reservoir Areas. Figure 5 shows the plot of the spectral reflectance ratio of band 7 and band 5 for Pinole and San Luis Reservoir Test Sites.

RESULTS

Manual Analysis of LANDSAT Imagery for Monitoring Plant Growth and Range Condition

Color Plates I and II show LANDSAT images (color composites) and ground photographs taken at eight dates during the 1972-73 growth period of the annual rangelands in Central California. This photo sequence shows the foothills at the Pinole Test Site in a dry condition on October 6, 1972, prior to complete germination. Sufficient rainfall had fallen on September 26, 27, 1972, to cause partial germination of annuals on the bottomland sites. However, evidence of this partial germination is not present in either the ground photo or the LANDSAT image. New plants were obscured by dry residual material from the previous season as seen on the LANDSAT image, where the foothills appear a tan color characteristic of dry vegetation. A second storm occurring between October 7 and 13, 1972, produced more than sufficient rainfall to cause complete germination of the annuals in this region, so that by October 24, 1972, the foothills appeared green with the new growth of the annual plants. This initial transformation in the appearance of the annual rangeland is dramatically illustrated by the LANDSAT image taken October 24, 1972, where the foothills around the Pinole Test Site appear reddish, corresponding to the presence of a new cover of green plants. Initially, growth was rapid, but the cold winter temperatures eventually suppress the growth rate. The January 4 photographs (LANDSAT and ground) show a subtle change from those of October 24, corresponding to a relatively small increase in cover and volume of annual plants. Cattle were introduced to this rangeland during the last week of November; thus, the appearance of the range in January is affected by the winter conditions affecting growth, by moderate grazing pressure, increased soil moisture and low sun angle.

In the grazing region containing Pinole Test Site, warming temperatures caused increased growth beginning in February. Growth remained rapid reaching peak foliage development in mid April. In grazing regions to the south the rapid growth period started earlier and was much shorter relative to the Pinole area.

The LANDSAT and ground photograph taken April 4, 1973, shows the foothills appearing at near their maximum green stage, considering the different stages of development on the different sites (bottomland, midslope and upland) which characterize this grazing region. The intensity of red coloration seen on the LANDSAT image (April 4) indicates the annual range is near its peak green condition. It should be recognized that at this time, plants on the upland sites had already formed inflorescence, while plants on the midslope and bottomland sites had inflorescence which had only recently emerged or were just emerging, respectively.

By April 22, forage plants on the upland sites had begun to dry, while plants on midslope and bottomland sites had developed inflorescence. This change is noted on the LANDSAT image by a subtle shift in color from red to red-orange for the Pinole Test Site. The first indication of widespread drying of the annuals can be noted in the grazing region south and east of the Pinole Site. Here the foothills appear a yellow-orange color characteristic of widespread drying of annual vegetation.

By May 10, all vegetation on upland sites in the Pinole Test Site had dried. Many of the plants on the midslope sites had also dried, and plants on bottomland sites had well developed inflorescence with foliage remaining green. On the corresponding LANDSAT image, the Pinole Range Site appears an orange color. Along the East side of the Coast range the annuals associated with the low rainfall--foothill areas (including the annuals at San Luis Reservoir), had completely dried as evidenced by the yellow color of these areas on the imagery. By May 28, most of the annuals associated with upland and midslope sites had dried, and drying had begun on bottomland sites. The LANDSAT image shows the foothill area around Pinole as a yellow orange color. Note that on this LANDSAT image most of the annual vegetation on the foothills to the east and south had already dried. By June 15, all of the annual plants associated with the foothills in the Pinole Test Site had dried. The LANDSAT image accurately depicts this condition, as evidenced by the yellow or straw colored appearance of the foothills throughout the grazing region. The colors of the dry rangeland are much brighter than those seen on the October 6, LANDSAT image because there is much more residual dry material. Throughout the summer, continued grazing use and/or natural deteriorating would cause the rangeland to return to an appearance very similar to that seen on October 6, 1972.

The sequence of LANDSAT images with the corresponding ground photographs that show range conditions in more detail, demonstrate that if LANDSAT images are cloud free during critical periods of the growth cycle of the annual range, one can monitor the timing of these growth stages and accurately assess the condition of the range plants. The growth stages which are critical are: the period of germination, the time of peak foliage development which coincides with the time that most of the plants have inflorescence in the dough or green stage, and the period of drying. To the extent that these stages can be documented, managers can determine the length of the green feed period, the time when the foliage is near its peak nutritional quality, the time when drying occurs, which reduces the quality of the forage, fuel hazard, and the availability of green forages. The time when these phenological events occur in relation to the expected or average time of occurrence can signal whether the current forage crop is below average or above average; hence, forage production can be inferred from a prior knowledge of the average timing of growth stages. Moreover, the large area coverage of LANDSAT provides a means for determining the progression of growth in the different grazing regions of the California Annual grassland. Thus, in any given year, drought affected areas or areas receiving below normal amounts of rainfall, (hence lower forage production) can be located, and the areal extent of these areas determined. Similarly, LANDSAT images can also show rangelands where above normal rainfall distributed throughout the growth cycle has resulted in a prolonged green feed period resulting in greater forage production and livestock weight gains.

Thus, manual interpretation of LANDSAT color composites can accurately determine the timing of three critical growth stages. However, cloud coverage during any of these periods substantially reduces the advantage of LANDSAT for acquiring this information in comparison to conventional methods. To reduce the possibility of acquiring unsuitable coverage during the critical stages, additional satellites or more frequent coverage would be required. As an alternative, light aircraft could be used for reconnaissance purposes during critical observation periods if cloud coverage was known to obscure the rangeland at the time of LANDSAT overpasses. In spite of the problem presented by cloud

coverage, cloud-free images permit one to estimate the portion of rangeland which has already dried, rangeland which is drying, and rangeland which is still green. Such an assessment can be used to predict the amount of animal movement from the range, and determine where the movement originates. Moreover, one can determine which areas are still green and make predictions regarding the amount of time that the forage would remain green, given particular weather conditions. Finally, maps showing different seasonal conditions could be produced each year for comparison with known conditions on previous and subsequent years, and statements regarding present conditions (greenness or dryness; or productivity) in relation to past conditions could be made. The value of these interpretations can be realized through better planning, predictions, and wiser decisions regarding rate and location of animal movement, need for supplemental feed, amount and location of residual dry material which causes critical fire hazard, and amount and quality of green feed in relation to (a) previous years or (b) an established normal.

Color Plate III shows a LANDSAT-2 color composite of rangelands adjacent to the San Francisco Bay Area, taken on January 24, 1975. When compared with the LANDSAT-1 image dated January 4, 1973 in Color Plate I, one can readily detect differences in the colors associated with the rangeland vegetation. The dull pink colors in the LANDSAT-2 image (January 24, 1975), correctly signify that forage growth had not progressed as rapidly for the 1974-75 growth season compared with the 1972-73 growth season. In fact, rainfall during the 1974-75 season was 50-60% below normal at the time the LANDSAT-2 image was taken. Not only was plant development slow, but forage production was also below normal. Ranchers were obliged to reduce number of livestock and/or provide feed supplements for a longer period of time. The important value of the LANDSAT data is in providing a permanent, unbiased record for comparing range conditions at approximately the same time period in two different growing years.

Monitoring Plant Growth and Range Conditions: Quantitative Analysis of LANDSAT Tapes and Ground Spectral Reflectance Data

Ground spectral reflectance data.- Throughout the 1972-73 growth season ground spectral reflectance (reflected radiant energy) measurements were made at frequent intervals at the Pinole Test Site. For the most part, reflectance measurements were made at randomly selected locations on both grazed and ungrazed bottomland, upland and midslope sites. Once a spectral reflectance measurement had been obtained, the plot was clipped, and the weight of the forage recorded. The spectral reflectance values corresponding to 675 and 800 nanometers were formed into a ratio and this ratio plotted over time for the growth season. Figure 2 permits a comparison of the spectral reflectance ratio curves for three sites in the Pinole Test Site with the corresponding green forage production data (oven dried) associated with the same range sites.

The similarity between the spectral reflectance ratio curve and the green forage production curve can be seen in Figure 2. The spectral reflectance ratios increase dramatically at the outset of the growth season corresponding to the period when germination has occurred. That the ratio for the upland site was so high can be explained in part by the complete cover of new vegetation and partly by the reflectance characteristics of the species occupying these sites. The ratios decrease markedly at the end of the growth season corresponding to the drying period prior to complete senescence of the forage crop.

The time when the spectral reflectance ratios peak is of particular importance. For each site, both grazed and ungrazed, the peak of the ratio curve occurs at the growth stage corresponding to early inflorescence development. This growth stage occurs just prior to the time when foliage production is at its peak and the nutritive quality of the

forage is also near maximum. It should be noted that the ratio curve peaks first for the upland site, followed by the intermediate and then the bottomland site. The time of these peaks and the order of their occurrence are consistant with the documented phenological ground conditions at these sites which are diagramed in Figure 2.

Finally, the relative difference in magnitude of the peaks of the ratio curves correspond with the relative difference in the forage production curve peaks associated with the three respective sites. These data indicate that the spectral reflectance ratio (800/675) is a sensitive indicator of the relative difference in green forage when different sites are compared. In addition it appears that the peak of the ratio curve coincides with the period when the forage is at its peak green stage, just prior to maximum foliage production.

LANDSAT spectral reflectance data.- LANDSAT spectral radiance data for the Pinole and the San Luis Reservoir Test Sites was extracted from LANDSAT computer compatible tapes. The average radiance value and the standard deviation of this mean for the two 6 x 6 picture element areas were determined from LANDSAT tapes acquired on August 13, and October 6, 1972, and January 4, April 4, April 22, May 10, and May 28, 1973. The average radiance for each of the four MSS bands is plotted against the date of acquisition in Figures 3 and 4 for the Pinole Test Site and San Luis Reservoir Test Site, respectively. These two Test Sites were selected for comparison because they occur within the same LANDSAT frame, and because they are in two different rainfall zones. The Pinole Test Site is in a 50 cm. rainfall zone having a green feed period of about 7½ months; whereas, San Luis Reservoir Site is in a 25 cm. rainfall zone having a green feed period of about 6 months.

An examination of the LANDSAT radiance curves for Pinole and San Luis Reservoir Test Sites reveals that the radiance values for all spectral bands decreases from the dry summer stage to the period of first rainfall or germination. Once the annual plants have germinated the infrared bands 6 and 7 increase in reflected radiance in response to increasing cover and density of forage. The visible bands 4 (green) and 5 (red) decrease in reflected radiance due to absorption of these wavelengths by the plants, and remain fairly constant through the slow growth period during the winter months. When growth begins to accelerate in late winter and early spring, reflected radiance in the infrared wavelengths increases rapidly while the visible wavelengths increase very slowly. Both infrared radiance curves (bands 6 and 7) peak when inflorescence are developing. This is also when the forage is at its peak green stage, just prior to maximum green forage production. The radiance curves for the infrared bands decrease in response to the drying of the annual vegetation. LANDSAT radiance for bands 4 and 5 increases rapidly during the time period coinciding with inflorescence maturity and the onset of drying on the shallow sites. Approximately 1 month after radiance in the infrared bands has reached a peak, radiance values from bands 4 and 5 cross over, due to the more rapid increase in radiance of band 5 compared to band 4 during this period. This rapid increase in band 5 radiance is correlated with the period of rapid drying of the annual forage. Moreover, this cross-over period occurs when forage on approximately half of the range sites is dry, while the other half is green and maturing. Once all the annual vegetation has dried, the radiance curves return to approximately the same level as those for the summer stage in the previous year. The late spring (1973) radiance levels are slightly above the radiance levels for the previous summer, (1972) because a greater amount of dry residual material remains on the sites at the outset of the summer of 1973.

The shape of the LANDSAT radiance curves is similar for the Pinole and San Luis Reservoir Test Sites (Figure 3 and 4, respectively) despite differences in the amount of forage produced and the length of the green feed period. For example, at both Test Sites the outset of germination was indicated when radiances from all four bands are very nearly

the same, and from which point the infrared bands increase while the visible bands decrease in radiance value. Notice this separation point occurs in mid-October for the Pinole Site, but does not occur until early November for the San Luis Reservoir Site. (This is consistent with the ground observations.) The radiance curves for the infrared bands peak in mid-April at Pinole and prior to early April at San Luis Reservoir Site. These peaks coincide with the time when the annuals were at their peak green stage and when green forage production was near maximum. Radiance values from bands 4 and 5 cross over in mid-May at Pinole and mid-April at San Luis Reservoir Site. These crossovers coincide with the period when half of the forage was dry at each site, respectively.

The conclusion to be drawn from these curves is that LANDSAT radiance data appears to provide a quantitative measure of the time of germination, the time of peak greenness or near maximum forage production, time when half of the forage is dry, and the time when drying is complete. This information permits determination of the length of various growth stages throughout the life cycle of the annual forage plants. The LANDSAT spectral data correctly revealed that annual plants germinated later, and matured and dried earlier at San Luis Reservoir compared to similar plants at Pinole.

LANDSAT radiance data from band 7 and 5 were formed into a ratio (7 over 5), and plotted over time (the dates of acquired cloud free LANDSAT Data). The radiance ratio curves for both Pinole and San Luis Reservoir are plotted in Figure 5. The curves reach a low point at or before germination. The ratio curves peak during the spring coinciding with the occurrence of peak foliage production. Thereafter, the curves fall signaling the period of drying following the maximum green period. Once the curves level off, one can conclude that all annual vegetation has dried.

The LANDSAT radiance ratio curve for Pinole is an integration of reflected radiance from bottomland, midslope and upland sites which are contained within the 36 picture element study area. This curve compares favorably in shape with the ground reflectance ratio curves for each range site seen in Figure 2, if one disregards the high reflectance ratios measured on the ground early in the growth season.

When the LANDSAT radiance ratio curve for Pinole is compared with the one for San Luis Reservoir (Figure 5), one can observe the difference in timing of critical growth stages. Moreover, the difference in magnitude for these two curves corresponds to the relative difference in forage production at the two range sites. Thus, the LANDSAT radiance ratios appear to provide a valid quantitative method for comparing relative differences in forage production for different grazing regions throughout the annual grassland, as well as assessing the timing of growth stages, and determining range condition (greenness or dryness).

DISCUSSION

Monitoring Growth Stages and Condition of Annual Forage

Although a complete sequence of cloud free LANDSAT images was not obtained, coverage at the critical growth periods was available for the San Francisco Bay Area frame to demonstrate that the time of growth events, the stage of plant development, and the condition of the annual forage can be determined from manual interpretation of LANDSAT imagery. The critical stages which must be monitored, in order to assess the relative length of the green feed period, to assess relative productivity and forage quality, and to determine the availability of green forage, are the period of germination, the peak of

the green foliage production stage, and the period of drying. If LANDSAT coverage is not available or of unusable quality due to cloud coverage, then supplemental data would be required. This could be in the form of ground reconnaissance or aerial reconnaissance from a light aircraft. If, however, supplemental data is required for more than one of the three critical growth stages, the efficiency gained from interpreting LANDSAT imagery decreases.

Whereas manual interpretation of LANDSAT imagery appears to be sufficient for identifying forage growth stage and condition, the element of interpreter subjectivity is inherent in the analysis of the images. Interpreter subjectivity by itself is not sufficient reason to discount the potential beneficial applications for using repetitive satellites to monitor changes in the condition of the California annual grassland, but an operational system which proposes to not only determine range conditions but provide predictions of forage production and extended length of the green feed period, of necessity requires more quantitative methods. Consistent with this need, the results from analysis of ground reflectance measurements coupled with analysis of LANDSAT spectral radiance data, indicate that changes in spectral reflectance characteristics of the annual grassland provide the quantitative indicators of plant growth stage and range condition. Specifically, the spectral radiance data from the LANDSAT MSS bands, and ratios of selected bands appear to provide accurate indicators of germination, peak of green foliage development, and the drying period. Moreover, the shape and magnitude of these reflectance data curves plotted over time provide a measure of the relative difference in condition and production and a measure of the differences in timing of growth stages between sites or grazing regions. To the extent that LANDSAT data is available at similar dates in different growing seasons, one can determine differences in time of growth stage and productivity between years. This may be as important an application of LANDSAT data as monitoring differences in development of the different grazing regions within a single season.

The criteria required for an operational monitoring system would include: (1) cloud free LANDSAT tapes (corrected for atmospheric differences) from representative Test Sites or analogous alternative sites during critical growth periods which will occur at different and unpredictable times at the different grazing regions within the state; (2) less than one week turn-around time for receipt of tapes during the peak of foliage development and the drying period; (3) backlog of phenology and production data upon which to make predictions of remaining length of green feed period, and regression equations for relating LANDSAT spectral reflectance (radiance) values to estimates of forage production; and (4) a medium for disseminating data to potential users. The LANDSAT system is vital in acquiring the data base required for the surveillance of the annual grassland for the following reasons: The annual grassland encompasses a large area (approximately 8-10 million hectares); the range of annual grasslands in the state encompasses many different environments from the 12 cm. rainfall zone to the 100 cm. rainfall zone, from sealevel to 1000 meters, and a wide temperature range throughout approximately 8 degrees of latitude; the repetitive coverage over the same areas, the use of scanner data and transmission equipment shows different range areas under the same lighting making comparisons of sites valid.

Determining Relative Amount of Forage Within and Between Seasons

Estimating or predicting the amount of forage produced within a given grazing region for a given year is a difficult yet important task for managers of forage resources. Conventional methods are generally inadequate or unrepresentative of large areas to provide a valid assessment of the quantity of forage produced within and between seasons. However, the feasibility of using remote sensing data to estimate or predict forage biomass is

demonstrated both in the literature (Tucker, Miller, and Pearson, 1973; Rouse, 1973; Maxwell and Johnson, 1974) and by the relationships discussed in this study. Namely, that relative differences in forage production for different sites in the same area (Pinole) correspond closely to difference in measured ground spectral radiance from the forage at these sites. Moreover, relative differences in forage production at two different grazing regions (viz. Pinole and San Luis Reservoir) are expressed in this study by measured differences in LANDSAT spectral radiance data extracted directly from the LANDSAT tapes. What is common to these methods for assessing forage production is the apparent high correlation between spectral reflectral ratios in specific bands (viz. the red and near infrared bands) and green forage biomass. Deviations from this relationship were noted early in the growth season when high reflectance ratios did not correspond to high biomass values. Unusual reflectance values were explained by active plant metabolism and by morphological characteristics of the plants during an early stage of growth. Although atmospheric haze was not a problem in this study, it is not known to what extent atmospheric conditions could invalidate the close relationship between biomass and reflectance characteristics.

Although the feasibility of assessing relative differences in forage production within and between sites is encouraging, range managers still seek reliable data regarding the estimated amount of standing biomass. Such estimates can be obtained using regression equations which regress LANDSAT spectral radiance data with ground sampled forage production data. Further study is needed in the area of ground sampling required to provide valid forage production data to be compared with the LANDSAT spectral data. The problem is that a single LANDSAT picture element or a group of LANDSAT picture elements may integrate many range sites with varying amounts of forage production. Thus, it is important to obtain ground samples in such a manner as to determine average forage production associated with a single or group of picture elements.

A second approach to estimating forage production using direct inputs from LANDSAT imagery is based upon prior knowledge of the average forage produced (in a given area) associated with an average growth cycle. Here, departures from the normal growth cycle as expressed by the length of the green growth period and by the condition of the forage, combined with measured departures of LANDSAT spectral reflectance data provide the indicators of below or above normal forage production. Whereas, assessment of below or above normal conditions favorable for below or above normal forage production is still qualitative, the use of regression models (simple or multiple regression) which incorporate LANDSAT spectral reflectance data, ground data and climatic data where appropriate, enables more quantitative predictions of forage production to be made. Within a growth season, some grazing regions may experience above normal conditions for growth, while others experience normal or below normal conditions for growth. Provided that the normal conditions are known for each of these grazing regions, one can determine relative differences in production between grazing regions for a given season. Similarly, when the average conditions are known for a given grazing region, departures from this average can be monitored using LANDSAT data and differences in forage production between seasons determined quantitatively. The extent to which assessment of length of green growth cycle and forage production can be made efficiently for large grazing areas depends upon the availability of LANDSAT data obtained at critical periods during the growth cycle. To determine the length of the growth cycle which is one variable closely associated with the amount of forage produced, one must acquire cloud free coverage during the germination period and the maturation and drying period at the end of the cycle. In order to assess differences in amount of forage through analysis of LANDSAT spectral data, the LANDSAT data must be acquired at the peak of the green forage production stage. Differential drying of plants after this period, causes radiance ratio values to decline although there may continue to be a small increase in total forage produced.

LANDSAT Imagery as a Means for Locating Available Forage

In Color Plate I the greenness or dryness of the forage can be determined visually upon inspection of the LANDSAT images. Moreover, the location of the areas possessing green forage during the latter portions of the growth cycle can be readily determined. Since this may vary from year to year, the LANDSAT monitoring system provides a potentially valuable tool for determining areas which either have abundant green forage due to favorable amount and distribution of rainfall, or areas which have dry forage relatively early in the growth cycle due to unseasonably low rainfall.

Because the LANDSAT spectral radiance response curves (Figures 3 and 4) indicate changes in the condition (greenness or dryness) and phenology of the forage, a quantitative approach to determination of forage condition and location is made possible. Furthermore, because of the distinctive spectral radiance differences between green and dry forage, automatic classification is a feasible and accurate method for determining the location and the area of range land which contains green healthy forage.

SUMMARY AND CONCLUSIONS

In this feasibility study LANDSAT imagery and magnetic tapes were analyzed to determine their utility for monitoring and assessing range condition within the annual grassland in California. LANDSAT data, forage samples at selected range sites, and ground spectral reflectance data were all examined in order to verify the usefulness of LANDSAT imagery for determining range condition, growth stage and assessing relative forage production. The results of ground spectral reflectance data compared with green forage production data show a close correspondence between spectral reflectance ratios and green biomass. Changes in ground spectral reflectance data also correspond with observed changes in growth stage and condition of the forage species. Moreover, LANDSAT spectral reflectance data provides quantitative signals of significant growth stages in the development of annual forage species. Relative differences in forage production are also indicated by the LANDSAT spectral radiance data.

It has been illustrated that LANDSAT color composite images provide a visual picture of the condition of the rangeland. Repetitive sequences of these images provide the means for monitoring change in condition and comparison of condition of different range areas. When LANDSAT spectral radiance data is extracted from specific range sites, one can determine quantitatively the occurrence of germination, the peak of foliage production, and the period of drying from spectral curves constructed from a sequence of LANDSAT images. In addition, ratios of spectral bands, namely 7 over 5, provide a sensitive indicator of changes in growth stages and an indication of the relative differences in forage production when two or more range areas are compared.

Provided that cloud free LANDSAT coverage is available during critical growth stages of the annual plants, namely, germination, peak of foliage production and period of maturation and drying, LANDSAT data can be used to: (a) assess differences in range condition on a regional basis; (b) compare differences in production between grazing regions for a given year; and (c) compare differences in condition and production for a given site between years. Moreover, the length of the green feed period can be determined and this information along with ground samples of forage production and climatic data can provide the inputs to simple models for estimating forage production or determining the remaining length of the green feed period beyond a definable threshold date late in the growth cycle of the annuals.

The anticipated benefits from LANDSAT monitoring of annual range vegetation include: (1) more accurate determination of germination and drying periods for planning movement of grazing animals to or from annual grassland ranges; (2) predictions of the remaining length of the green feed period made early enough to plan more efficiently for alternative sources of livestock feed; (3) comparison of conditions and relative forage production between grazing areas within a season, and comparison of condition and productivity for a given area between seasons; (4) determination of time when dry forage creates a fire hazard in order to better allocate men and equipment for fire suppression; and (5) assess extent and location of grazing areas influenced by abnormal climatic conditions, be it drought or abundance of forage.

References Cited

Biswell, H.H., 1956. "Ecology of California Grasslands," Journal of Range Management, 9:19-24.

Carneggie, D.M., and S.D. DeGloria, 1973. "Monitoring California's Forage Resource Using ERTS-1 and Supporting Aircraft Data," Symposium on Significant Results Obtained From ERTS-1, New Carrollton, Maryland.

Hart, G.H., H.R. Guilbert, and H. Goss, 1932. "Seasonal Changes in the Chemical Composition of Range Forage and Their Relation to Nutrition of Animals," University of California, Agriculture Experiment Station, Berkeley, Calif. Bulletin 543, p. 62.

Heady, H.F., 1958. "Vegetational Changes in the California Annual Type," Ecology 39, pp. 402-416.

Janes, Eric, 1969. "Botanical Composition and Productivity in the California Annual Grassland in Relation to Rainfall," Masters Thesis, University of California, Berkeley.

Maxwell, E.L. and G.R. Johnson, 1974. "A Remote Sensing Analysis System," Report No. 1885F, Colorado State University, Ft. Collins, Colorado.

Roberts, E.H. and M.J. Gialdini, 1973. "Seasonal Changes in the Spectral Character of Reflectance from Three California Annual Rangeland Sites," Proceedings from 2nd Annual Remote Sensing of Earth Resources Conference, Tullahoma, Tennessee. Edited by F. Shahrokhi.

Rouse, J.W., R.H. Haas, J.A. Schell, and D.W. Deering, 1973. "Monitoring Vegetation Systems in the Great Plains with ERTS," Third ERTS-1 Symposium, Volume 1, Section A, Goddard Space Flight Center, Washington, D.C., pp. 309-317.

Talbot, M.W., H.H. Biswell, and A.L. Hormay, 1939. "Fluctuations in the Annual Vegetation of California," Ecology 20, pp. 394-402.

Tucker, C.J., L.D. Miller, and R.L. Pearson, 1973. "Measurement of the Combined Effect of Green Biomass, Chlorophyll, and Leaf Water on Canopy Spectro Reflectance of the Short-Grass Prairie," Proceedings of Second Annual Remote Sensing of Earth Resources Conference, Space Institute, University of Tennessee, Tullahoma, Tennessee.

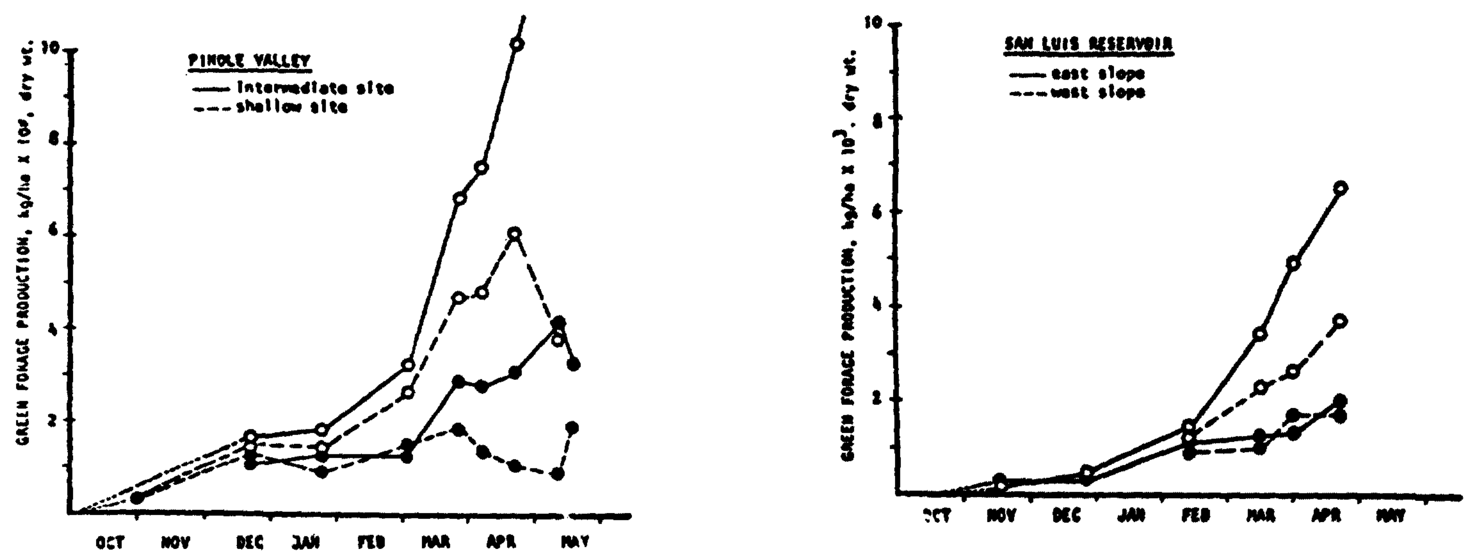


FIGURE 1. Total forage production, exclusive of residual material (over dry weight) at two of three sample sites at Pinole and at two sample sites near San Luis Reservoir. Samples were collected during the 1972-73 grazing season. Those made from ungrazed plots are indicated by an open circle. Note that forage production at Pinole is nearly double the production at San Luis Reservoir Test Site.

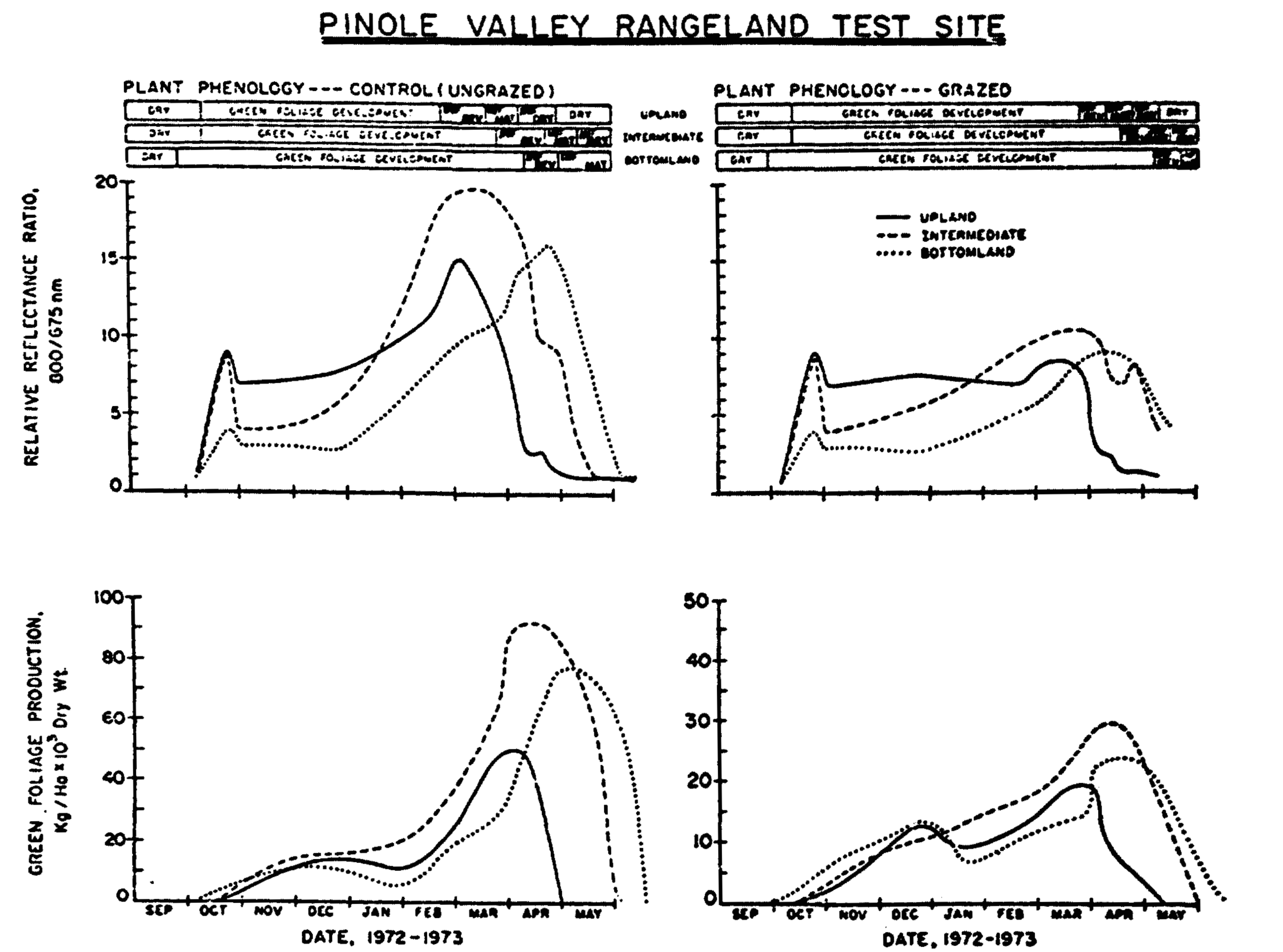


FIGURE 2 Green forage production and spectral reflectance ratio curves are plotted, and plant phenology is documented over time for three range sites at the Pinole Test Site. Note the correspondence of the shape of the curves (both production and reflectance) to changes in plant phenology as the annual grassland progresses toward maturity and subsequent drying. This correspondence is evident in both the grazed and ungrazed portions of the range sites. The phenological stages observed and documented include dry, green foliage development, inflorescence development (INF DEV), inflorescence mature (INF MAT), inflorescence dry (INF DRY) and dry.

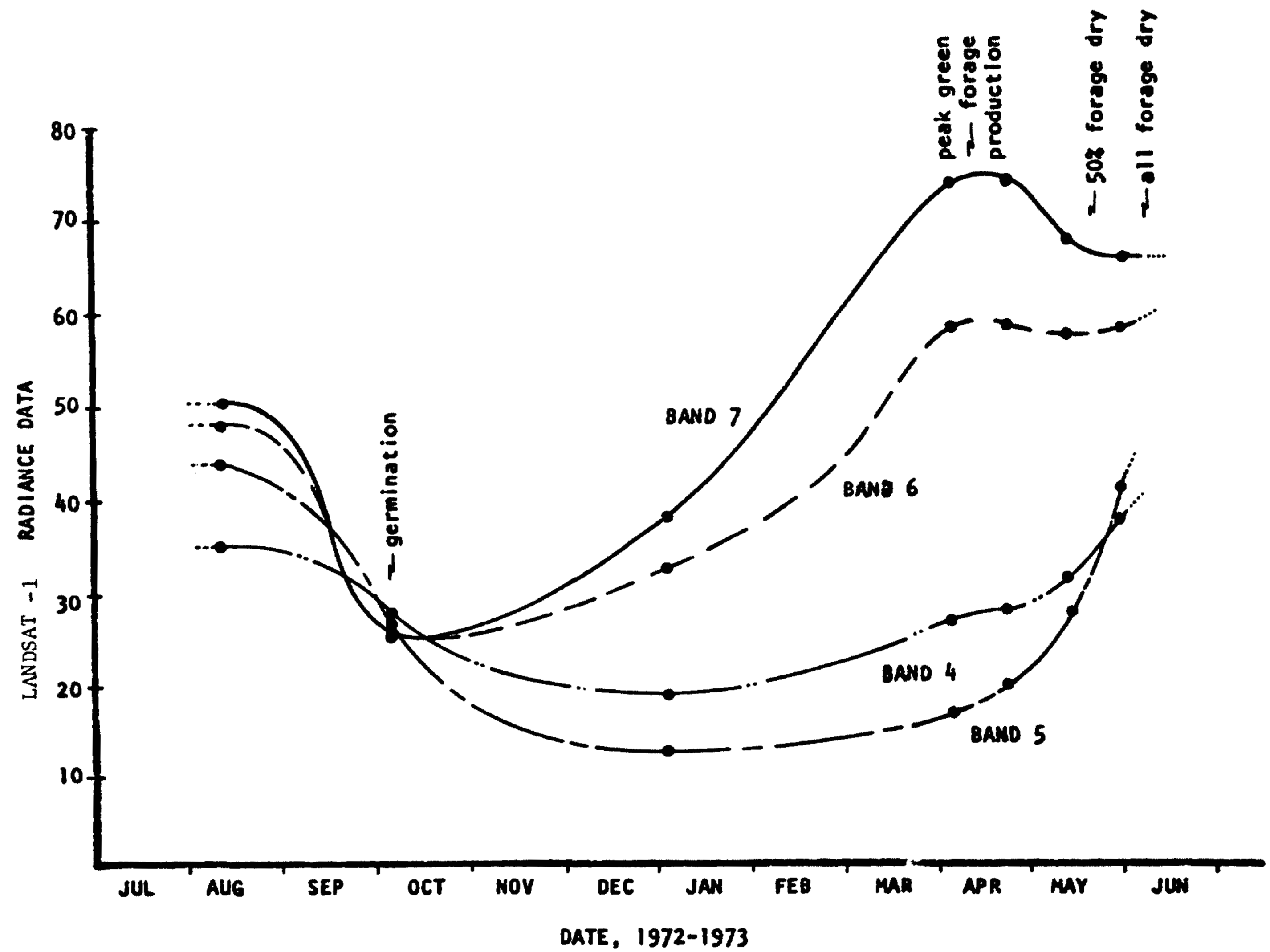


FIGURE 3. LANDSAT spectral reflectance curves for each MSS band (4,5,6,7) plotted over time for the Pinole Test Site. The data used in this graph was extracted from LANDSAT-1 tapes for a 6 x 6 picture element area which includes the study sites where ground data was collected. Note how changes in the curves correspond with phenological stages of plant growth.

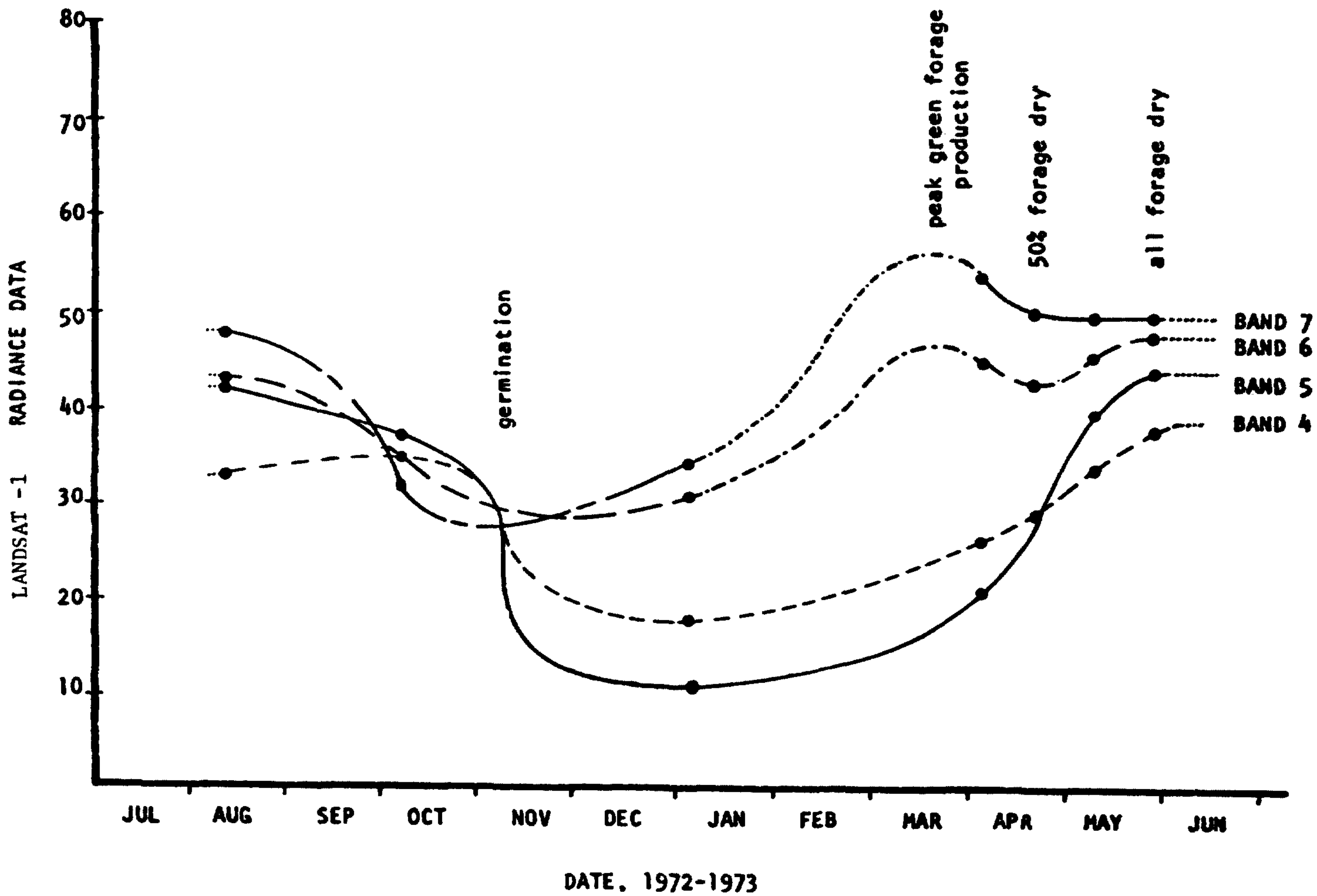


FIGURE 4. LANDSAT Spectral reflectance curves for each MSS band (4,5,6,7) plotted over time for the San Luis Reservoir Test Site. The data used in this graph was extracted from LANDSAT tapes for a 6 x 6 picture element area which includes the test site where ground data was collected. Note how changes in the curves correspond with phenological stages of plant growth.

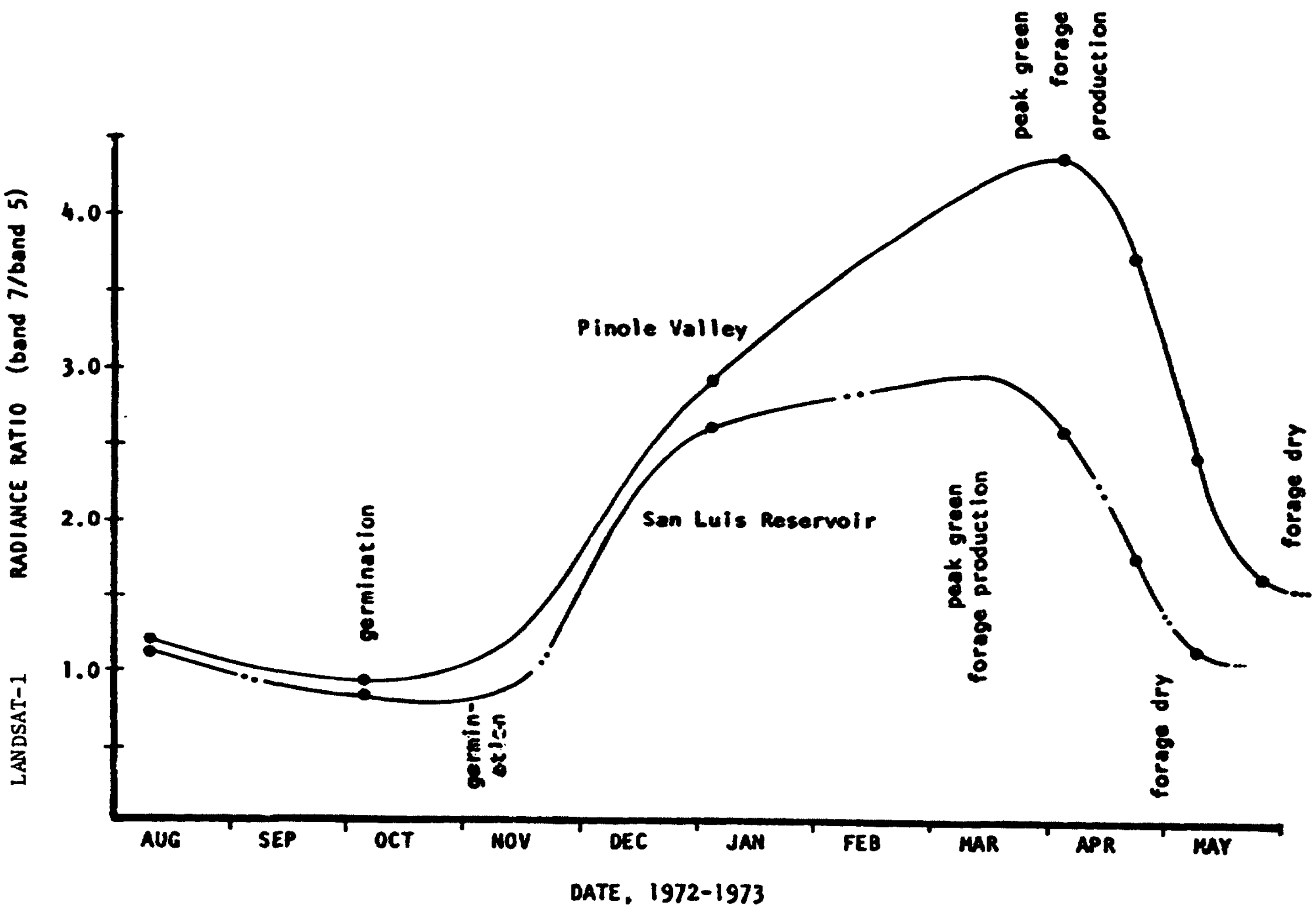
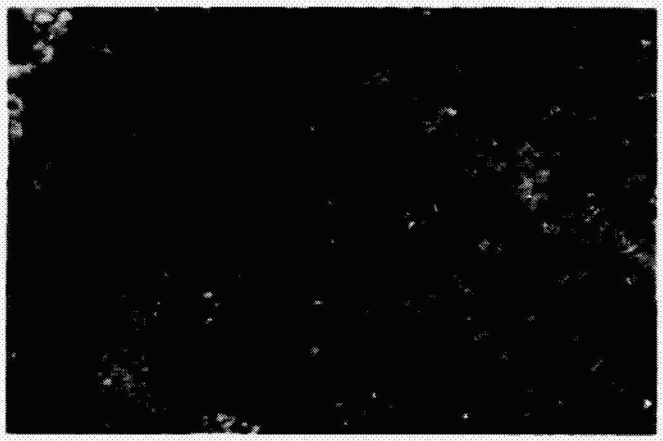
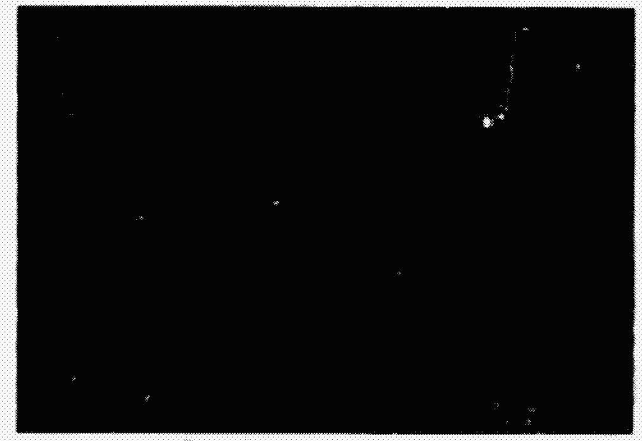


FIGURE 5. LANDSAT spectral reflectance ratio curves for the Pinole and San Luis Reservoir Test Sites. The ratio (band 7/band 5) is plotted over time for the 1972-73 grazing season. Note how changes in the curves correspond to the time of occurrence of phenological stages of plant growth. Difference in magnitude of the curves suggest the relative difference in forage production between the two sites.

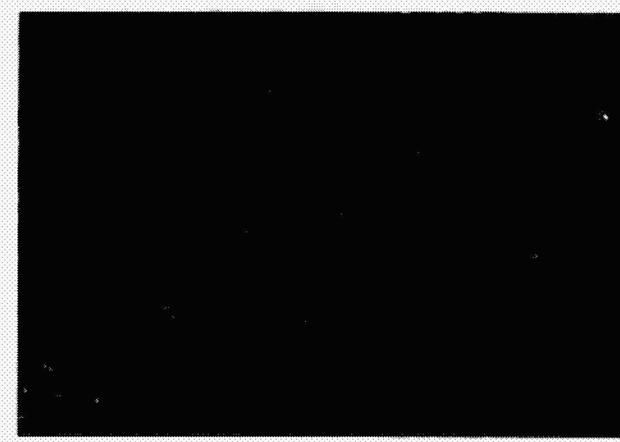


October 6, 1972



October 24, 1972

January 4, 1973

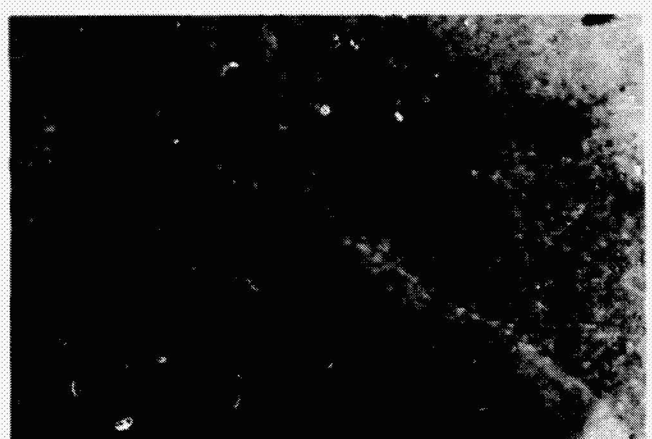


April 4, 1973

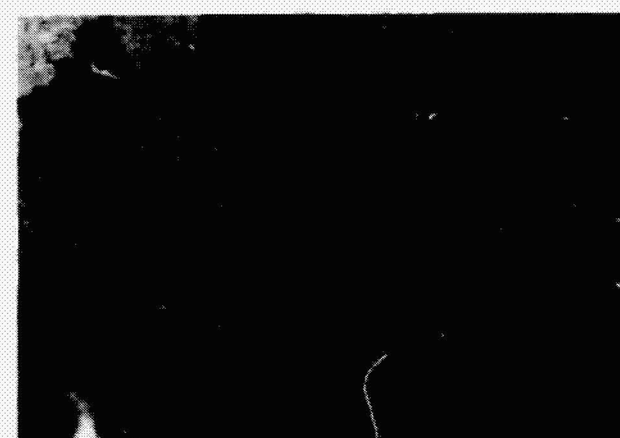
COLOR PLATE I. This sequence of LANDSAT color composites shows the changing appearance of the California annual grassland adjacent to the San Francisco Bay Area. The Pinole Test Site is located northeast of San Francisco, across the Bay and beyond the metropolitan area of the East Bay cities of Oakland, Berkeley and Richmond. The annual grasslands are readily identified on the October 6 color composite by their tan to gray color which indicate that the rangelands are still dry. Note that on subsequent dates germination and progressive plant growth account for the shift from tan to pink colors corresponding to the presence and vigor of the green annual plants. These rangelands reach a stage on April 4, 1973 where foliage production is near maximum, hence the bright red color seen on the LANDSAT color composite. Progressive drying beyond April 4 account for the shift in colors from bright red to orange to yellow. The ground photographs seen in COLOR PLATE II show how the annual rangeland appeared on the dates of the LANDSAT overpasses.

April 22, 1973

May 10, 1973



May 28, 1973



June 15, 1973

COLOR PLATE I. Concluded.

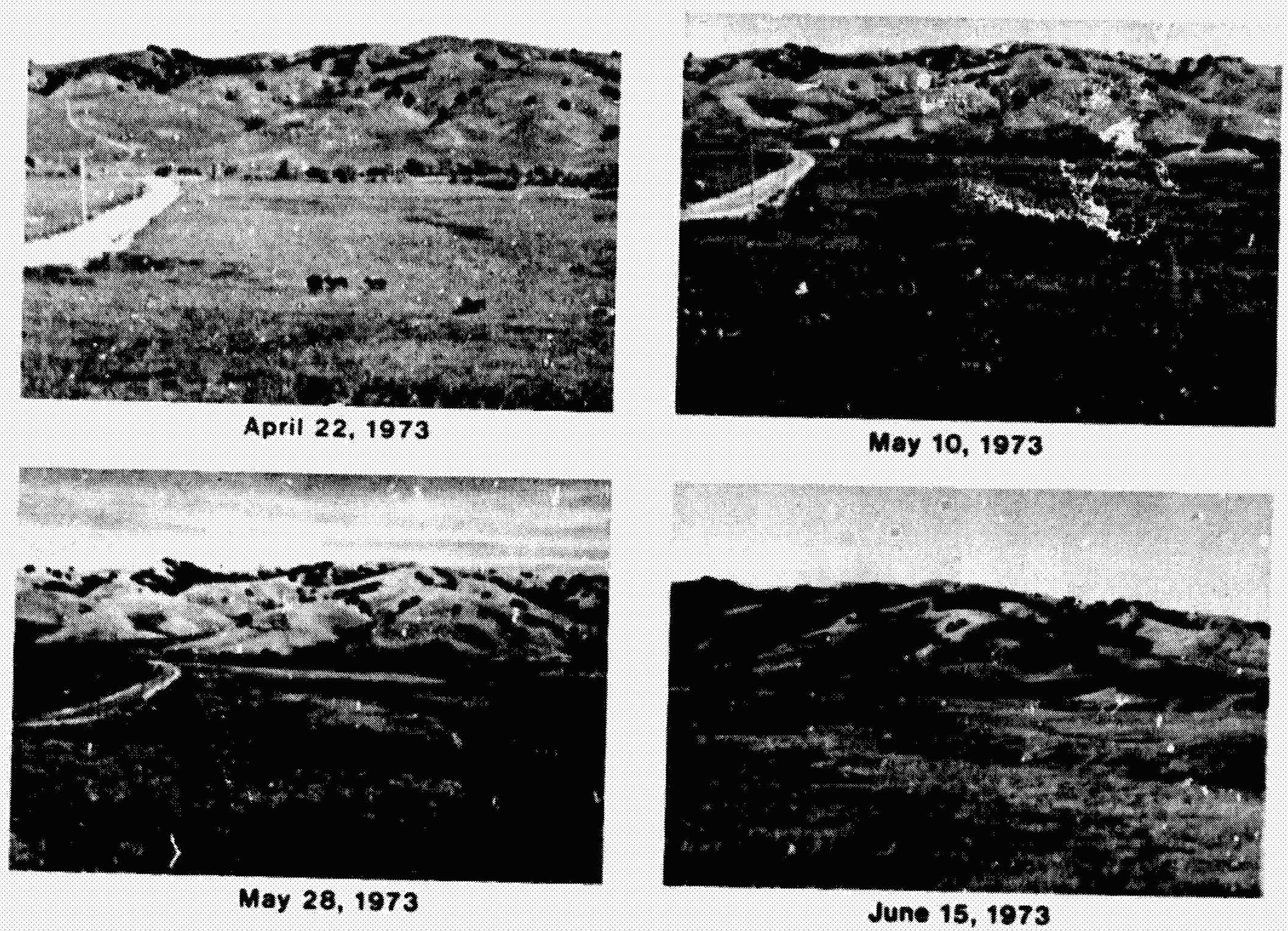
October 6, 1972

October 24, 1972

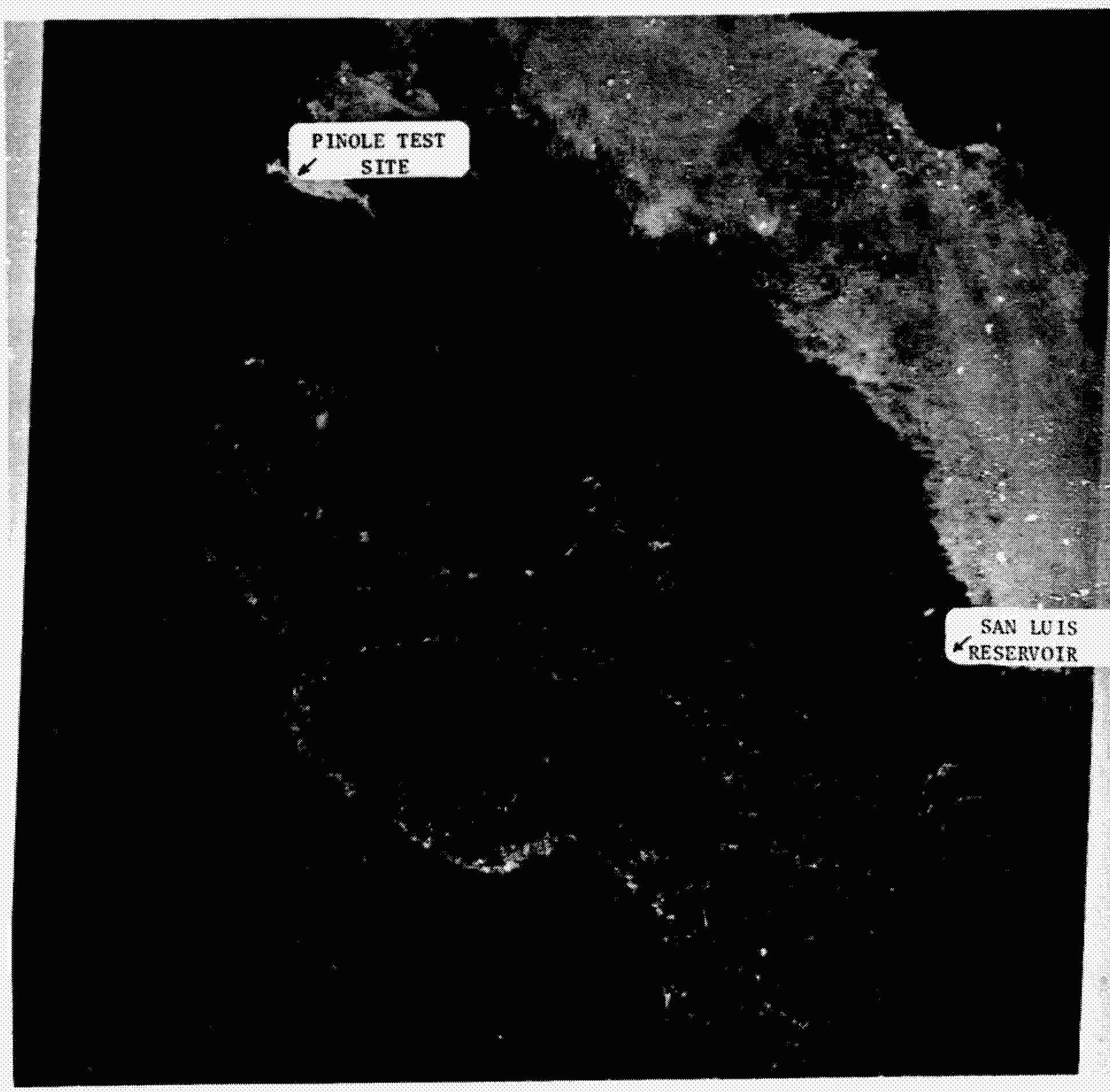
January 4, 1973

April 4, 1973

COLOR PLATE II. This sequence of eight ground photographs shows the changing appearance of the annual grassland range at the Pinole Test Site during the 1972-73 growing period. The dates of the ground photographs coincide with the dates of LANDSAT overpasses. The LANDSAT color composite images for the corresponding dates are seen in COLOR PLATE I. Note that germination of the annuals has occurred between October 6 and October 24, 1972. Note also that on April 4, 1973, the rangeland still appears green, but progressive drying of the forage plants is evident on subsequent ground photographs. In early April the forage plants had reached their peak for foliage production and were rapidly developing in florescence and maturing.



COLOR PLATE II. Concluded.



COLOR PLATE III. This LANDSAT-2 color composite of the San Francisco Bay Area shows the location of the Pinole and San Luis Reservoir test sites discussed in this paper. This image was taken on January 24, 1975, and provides an opportunity to compare range conditions in January 1975 with conditions in January 1973 (COLOR PLATE I). The relatively brighter pink color associated with the annual grasslands as seen on the January 4, 1973 LANDSAT-1 image correctly indicates that plant growth and forage production in January 1973 exceeded that in January 1975. Range conditions in January 1973 were normal or slightly in excess of normal, whereas in January 1975 range conditions were considerably below normal causing ranchers to reduce stocking rates and provide feed supplements to sustain their grazing animals.

N76-17473

A-4

MONITORING VEGETATION CONDITIONS FROM LANDSAT FOR USE IN RANGE MANAGEMENT

R.H. Haas, D.W. Deering, J.W. Rouse, Jr., and J.A. Schell
Texas A&M University
College Station, Texas

ABSTRACT

A summary of the LANDSAT Great Plains Corridor projects and the principal results are presented. Emphasis is given to the use of satellite acquired phenological data for range management and agri-business activities. A convenient method of reducing LANDSAT MSS data to provide quantitative estimates of green biomass on rangelands in the Great Plains is explained. Suggestions for the use of this approach for evaluating range feed conditions are presented. A LANDSAT Follow-on project has been initiated which will employ the green biomass estimation method in a quasi-operational monitoring of range readiness and range feed conditions on a regional scale.

INTRODUCTION

The Great Plains Corridor project conducted by Texas A&M University as part of the NASA LANDSAT investigations has yielded results of considerable significance to rangeland management and agri-business activities employing

phenology data. The objective of this project was to use satellite remote sensing data to observe natural vegetation systems both as forage crop and as phenological indicators throughout the Great Plains of the central United States. It was hypothesized that the vernal advancement and retrogradation of natural vegetation could be monitored using LANDSAT imagery and digital multispectral scanner (MSS) data. It was further assumed that natural vegetation systems used as phenological indicators of seasonal development would provide an important means of measuring bioclimatic effects on a regional basis.

The Great Plains Corridor Study has emphasized and developed techniques for quantitative analysis of LANDSAT MSS spectral radiance data as quantitative indicators of the amount and seasonal condition of rangeland vegetation. The techniques used are viewed as a viable alternative to qualitative assessments made through image interpretation.

The Great Plains Corridor project has also been responsible for the development of related LANDSAT activities in the Great Plains and especially in Texas. The spinoff projects have been user-generated; consequently, the investigation is impacting on established management efforts. These projects include monitoring the management of leased public rangelands and mapping wildlife habitat.

PROJECT ACCOMPLISHMENTS

Specific accomplishments achieved in studying the use of LANDSAT data for the quantitative assessment of natural vegetation are as follows:

1) An effective test site network consisting of ten primary test sites was established throughout the Great Plains Corridor. More than 217 sets of cloud-free satellite data and 200 sets of ground truth data were collected for the test sites involved in the study. Cooperators from state and federal agencies acquired vegetation measurement data at the time of LANDSAT overpass during the non-dormant seasons for a period of 23 months. Out of the data sets collected, 124 satellite data sets with corresponding ground data were utilized in the analysis.

2) An algorithm was employed and tested for correcting MSS digital data for changes in solar intensity as a function of solar elevation angle. Changing illumination conditions are a serious problem for making temporal comparisons of digital data values. The successful application of the solar angle correction model made it possible to compare digital data from frame to frame, cycle to cycle, and location to location throughout the duration of the investigation. Since development and application of atmospheric correction

algorithms was not an objective of this study, data requiring large corrections for haze or thin cirrus were omitted from the analysis.

3) The theoretical derivation of the normalized band difference led to the development of the Transformed Vegetation Index (TVI). Investigations early in the project led to development of the hypothesis that the normalized difference between the red and infrared bands was potentially useful for the quantitative measurement of green biomass. This potential was realized initially through the development of the Transformed Vegetation Index (TVI). TVI was formulated as the following ratio using MSS Bands 7 and 5 values:

$$\mathrm{TVI} = \sqrt{\frac{\text{Band 7} - \text{Band 5}}{\text{Band 7} + \text{Band 5}} + 0.5}$$

In the final analysis, it was found that the difference between Band 5 and Band 6 is generally more sensitive to the detection and quantitative assessment of green biomass differences. The new parameter is called TVI6, where Band 6 replaced Band 7 in TVI. R^2 values for TVI and TVI6 regressed on green biomass, plant moisture content and the combination of the two (Table I) illustrate the general superiority of TVI6.

4) Detailed statistical analyses show that the TVI6 parameter, along with limited weather data, is adequate to quantitatively assess rangeland feed conditions. Using the most extensive data set collected at a single test site (the Throckmorton, Texas test site), detailed statistical analyses show the potential for the use of the LANDSAT-derived parameter for the quantitative measurement of green biomass. A comparison of the LANDSAT TVI values to the green biomass measured at the Throckmorton test site is shown in Figure I. Factors such as moisture content of the vegetation, or the alternative use of precipitation and temperature data, are necessary for modeling a predictive equation for estimating green biomass to the desired accuracy.

With TVI6 as the dependent variable, a stepwise multiple regression analysis was performed to select the variables most likely to explain the variation observed in the LANDSAT observations. The best four-variable model is expressed by the following equation:

$$\hat{Y} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4$$

where $\hat{Y}$ = TVI6,

X_1 = green biomass (kg/ha)

X_2 = precipitation since last satellite overpass [18 days] (inches)

X_3 = precipitation on the day before the overpass (inches)

X_4 = maximum temperature on the day of the satellite overpass (°F)

These independent variables accounted for more than 90% of the variation in the TVI6 values. The above parameters were utilized to obtain a four-variable model with green biomass as the dependent variable and utilizing TVI6, precipitation during the previous 18 days, precipitation on day before the overpass and maximum temperature on overpass day as the independent variables. The ability to estimate green biomass in increments of 250 to 300 kg/ha with a 95% probability from TVI6 data and readily available weather data is indicated.

5) It was clearly demonstrated that the vernal advancement could be monitored through its northward movement in the Great Plains. Ground observations and satellite data collected in 1973 show that the vernal advancement progressed from the most southerly sites through the northernmost sites according to an expected progression calculated from the generalization commonly known as Hopkins Bioclimatic Law. It is of interest that in 1973, four of ten test sites were six days or more later than the expected progression and two

test sites were more than six days early. Spring developed as much as 18-20 days from the expected progression.

Observations from satellite data would be useful in monitoring the actual advancement of spring throughout this vast region for application to crop surveys. That is, these data can support phenological crop models or be used in determining crop calendars. The satellite data can be used to establish crop calendars based on phenological events for crop yield prediction.

6) The successful use of LANDSAT data for measuring green biomass had led to an approach for a follow-on investigation which will evaluate the use of LANDSAT data to monitor rangeland feed conditions on a regional basis. A quasi-operational system for monitoring range readiness and range feed condition is being developed using LANDSAT images, high-flight color-IR photography, soil maps, and topographic maps as data base information. After the vegetation/soils resource has been mapped for the region, the TVI6 plus precipitation and temperature values will be applied for quantitative determination of vegetation conditions at the time of satellite overpass. Vegetation condition will be contour mapped over a region in a manner similar to the maps now compiled by the Statistical Research Service, ARS, from

post card surveys. The potential also exists for mapping distribution of grazing use and forage condition on a pasture by pasture basis. These data will be disseminated to ranchers and range management organizations for use in their operations.

TABLE I. R^2 VALUES FROM REGRESSION ANALYSES OF LANDSAT BAND RATIO PARAMETERS AND SELECTED GROUND PARAMETERS FOR SELECTED G.P.C. TEST SITES.

Test Site	Green Biomass		Green Biomass + Moisture Content	
	TVI	TVI6	TVI	TVI6
Throckmorton	.7252**	.8254**	.8598**	.9117**
Chickasha	.2150	.3170*	.6799**	.8280**
Woodward	.6024*	.7749**	.6932†	.8509*
Hays	.5066**	.5410**	.5873	.6028*
Sand Hills	.8231**	.8003**	.8370*	.8293**
Cottonwood	.4264*	.5583**	.7455**	.7431**
Mandan	.7105*	.6346*	.9011*	.9531**

** regression significant at the 99% level of probability
* regression significant at the 95% level of probability
† regression significant at the 90% level of probability

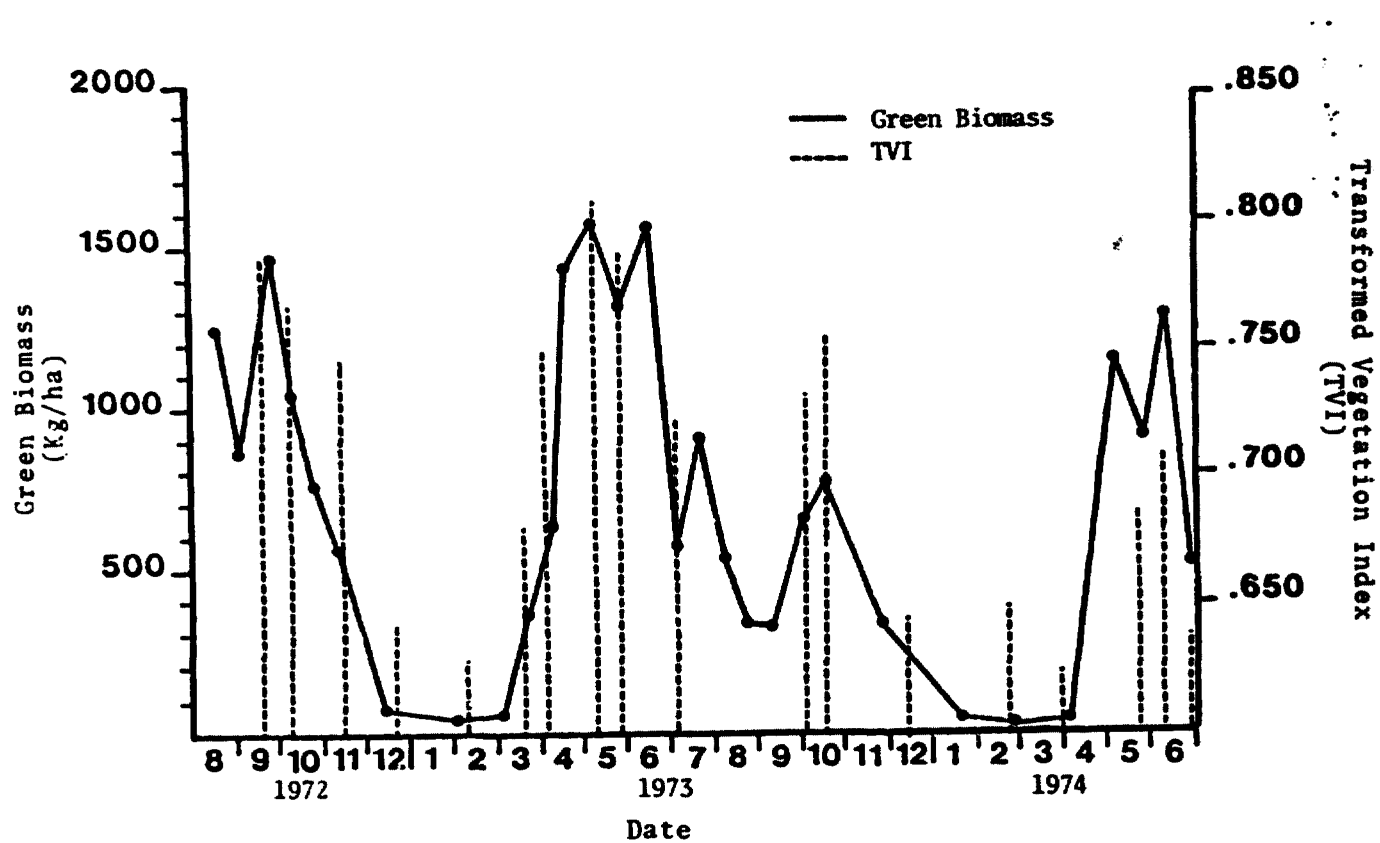


Figure 1. Graph showing the relationship of the transformed vegetation index (eighteen dates) and green biomass (all data) at the Throckmorton test site.

UTILIZATION OF LANDSAT IMAGERY FOR MAPPING VEGETATION ON THE MILLIONTH SCALE

A-5

By Donald L. Williams and Jerry C. Coiner, University of Kansas
Space Technology Center, University of Kansas, Lawrence, Kansas 66045

N76-17474

ABSTRACT

The United Nations Educational, Scientific and Cultural Organization (Unesco) has recently published a vegetation classification system. This system, based on the physiognomy of the vegetation, is designed to provide a comprehensive framework for the preparation of vegetation maps of any part of the world at scales of 1:1,000,000 or less. The utility of the system lies in the fact that optimal agricultural land uses are always related to the natural vegetation.

The system is designed for use with maps covering large areas. The large map area, however, poses a severe problem in uniform data collection, especially if large-scale imagery is employed as a mapping base. Since LANDSAT images have a basic utilization scale of 1:1,000,000, identical to that of the projected maps, they would serve as a uniform base for all parts of the world if they contained the information necessary to delimit vegetation formations.

To determine if the information content of the imagery is sufficient to permit mapping according to the Unesco classification, a series of test sites have been examined. These sites include examples from the humid tropics, arid and semi-arid subtropics and temperate zones. In every case the feasibility of this application of LANDSAT imagery has been verified. The agricultural significance of several sites is discussed to indicate how the vegetation maps may be interpreted for agricultural evaluation.

INTRODUCTION

In 1965 the Standing Committee on Classification and Mapping of Vegetation of the United Nations Educational, Scientific and Cultural Organization (Unesco) began consideration of a classification of vegetation. The Committee, composed of authorities from throughout the world, worked through the next decade to develop its classification. As published in its final form (ref. 1), this classification system is designed to provide a comprehensive framework for the preparation of vegetation maps of any part of the world at scales of 1:1,000,000 or less. Utilization of the system would result in the production of maps providing a solid basis for comparison of vegetation in all parts of the world.

The utility of such a system lies in the fact that optimal agricultural land uses are always related to the natural vegetation. Consequently, if successful production of a certain crop occurs in areas where ecological conditions produce a particular vegetation type, other parts of the world possessing the same vegetation type and, therefore, the same environment, will also be suited to the cultivation of that crop. As human populations continue to grow, it becomes ever more necessary to produce those crops best suited to each part of the Earth's surface to ensure the optimum availability of food and other agricultural commodities. This classification is therefore particularly relevant to large-area planning problems.

Prior to final publication of the system, field trials were conducted in Costa Rica by Küchler and Montoya Maquin (ref. 2). These trials established the feasibility of field classification of vegetation units under the system. Subsequently, Williams, et al. (ref. 3) mapped a small area in northeastern

Kansas. Although the map was published at a large scale (1:12,000), the feasibility of using the system was once again demonstrated. To date, no small scale map based on the Unesco classification has been published. Nevertheless, these results clearly indicate that the system is usable.

The classification is based upon physiognomic rather than floristic criteria. Physiognomy refers to the physical appearance or growth form of the vegetation while the floristic composition is the list of plant species which are present in a plant community. Although interconnected, physiognomy and flora are not identical. Thus, a given group of plant species may exhibit different physiognomies under different environmental conditions. For example, trees which form dense forests at lower elevations become reduced in size and tree density decreases near timberline. This changes the physiognomy of the vegetation from closed forests to open shrublands although the principal species are the same. On the other hand, different groups of plant species may exhibit identical physiognomies when growing under similar environmental conditions. This phenomenon has long been recognized in the wintergreen shrublands of California, the Mediterranean basin, southern Australia, South Africa, and Chile where the plants respond to the concentration of precipitation in the cool season. Because the Unesco classification is based upon physiognomy, it results in all such shrublands being assigned to a common class, accurately reflecting the comparability of environments in these areas (ref. 4).

The Unesco classification is an open-ended hierarchy with the formation as the basic unit of the system. As illustrated below, three levels exist above the formation. Although the definition is amplified in the text of the classification, the formation name is sufficient to inform the map reader that this

Classification Unit	Example
Formation Class	Closed Forest
Formation Subclass	Mainly evergreen forest
Formation Group	Tropical ombrophilous forest
Formation	Tropical ombrophilous swamp forest

example vegetation type is a forest, with tree crowns touching, composed of trees which are (1) broad-leaved; (2) evergreen; (3) grow in warm, very humid areas; and (4) are in permanently inundated localities. In preparing the classification the Committee designated some subformations, but the individual is free to add other subformations or further subdivisions and to augment the formation name with floristic data or significant local names of the vegetation type. The mapper might thus specify that his formation is locally known as chaparral in California and macchia in Italy.

Five formation classes have been designated by the Committee, encompassing all terrestrial and emergent aquatic vegetation known to occur. These formation classes are defined in the following manner (ref. 1).

Formation Class	Definition
Closed forest	Formed by trees at least 5 m tall with their crowns interlocking
Woodland	Composed of trees at least 5 m tall with crowns not usually touching but with a coverage of at least 40 percent.
Scrub	Mainly composed of woody plants 0.5 to 5 m tall.
Dwarf-scrub	Composed mainly of woody plants rarely exceeding 50 cm in height.
Herbaceous	Dominated by an herbaceous synusia and with woody plants not covering more than 40 percent of the area

Systems of subdivision used in each formation class are consistent within limits imposed by the characteristics of different plant growth forms and the range of naturally occurring vegetation types.

Cultural vegetation is treated as a separate and unique portion of the vegetation. Units of natural vegetation are used to infer ecologic conditions in cultivated and urbanized areas but such predicted areas are always distinctively indicated on the map.

Small-scale Mapping Methods

As detailed by Küchler (ref. 5), two basic methods exist for preparing small-scale vegetation maps. One of these methods is compilation. In compilation, all of the previously published vegetation maps of the study area are collected, common legend elements are extracted for a composite legend and the maps are compiled onto a common base. This method is feasible only if large- and medium-scale maps have previously been produced for the entire study area. Even then, substantial difficulties may arise because some maps may show floristic, others physiognomic, and still others ecologic classes and these legends may prove irreconcilable.

The second method of generating small scale vegetation maps is primary mapping. The principal components of this method are (1) acquisition of a set of aerial photographs, (2) delineation of vegetational boundaries apparent on these photos, and (3) a field survey to verify the boundaries and identify the vegetation units enclosed by these boundaries. In general, the products of primary mapping methods are considerably superior to products of compilation methods because of consistency of the legend classes.

Considering that the objective of the Unesco vegetation classification is to provide a basis for small-scale mapping and that the objective of small-scale maps is large-area coverage, primary mapping methods pose a serious problem. Areas suitable for inclusion on a single map sheet at the millionth scale may well be of the order of size of the state of Kansas, over 200,000 km^2. Over such an area, large scale imagery of uniform quality, scale, and date is rarely available. Even if such imagery were available, utilization poses a severe handling problem. Since each frame of 1:20,000 aerial photography represents a gain of approximately 5 km^2, about 40,000 frames of 9-inch format photography are required to cover the state. Nor is the standardly available imagery time-synchronous. In fact, the most current available set of photos for the state of Kansas have acquisition dates spanning a period of 16 years. The dollar cost and physical problems attendant on acquisition of a new set of images for such an area eliminate a special mission as a viable alternative. Since the actual surface area represented by the gain of one 1:20,000-scale photo will be portrayed by only 5 mm^2 on the finished map, most of the detail evident in the photo will have to be discarded during reduction. Acquisition of surface observations about all of the boundaries and types evident on the photo will represent large expenditures of wasted field effort. Further, the sheer mechanics of a 50 X scale reduction are costly and fraught with error potential.

In contrast to the problems of large-scale imagery specified above, LANDSAT images have a basic utilization scale of 1:1,000,000, identical to that of the projected maps. This scale effectively eliminates problems associated with reduction of the manuscript map and facilitates use of optimum current cartographic techniques. Parts of only 18 scenes are required to cover the state of Kansas, eliminating the aforementioned image handling problem. Although resolution is sufficient to record more detail than can be reasonably reproduced on the finished map, unnecessary detail has already been generalized out of the image by the acquisition process. The imagery provides a uniform mapping base for all parts of the world, thereby solving the difficulties of procuring a suitable base map.

Since it is evident that LANDSAT imagery would prove useful for vegetation mapping at the millionth scale, the remaining question must be whether the vegetational information contained in the images is that required for distinguishing formations as established in the Unesco classification.

MATERIALS AND METHODS

In order to test the feasibility of using LANDSAT Multispectral Scanner (MSS) imagery for vegetation mapping, a series of test sites was selected. These sites represent a wide range of physiognomic types, although they do not include every formation in the classification. Each test site was chosen on the basis of available MSS images and supporting data in either the form of direct observations by the authors or published maps and analyses of the vegetation amenable to use in the Unesco classification. The sites illustrated in this discussion are indicated on Figure 1, which also indicates several supplementary sites checked in the course of the investigation.

Color composite LANDSAT images were employed for interpretation of vegetation boundaries and the formations were determined by comparison with the supporting data. In addition, consideration was given to the image characteristics associated with each of the formations.

RESULTS

Results of this experiment are presented in the form of vegetation maps and annotated images which will serve to illustrate the detectability of various formations. The range of problems and potentials associated with small-scale vegetation mapping are indicated by Figure 2, which presents a vegetation map of a portion of the Western Highlands of Papua New Guinea together with the LANDSAT MSS image from which it was prepared. It should be noted that the image, although it exhibits the normal complement of colors, was prepared from bands 5 and 7 only. This was done because degradation of band 4 due to atmospheric scattering is extreme in very humid areas. Current experience indicates that loss of image sharpness (spatial resolution) due to incorporation of band 4 more than offsets any gain attributable to spectral differences between bands 4 and 5, as long as targets such as natural vegetation are under consideration. Except for the Papua New Guinea scenes, however, all composites used in this study are conventional combinations of bands 4, 5, and 7.

The basic relationships between image and map are readily apparent (Figure 2). However, a number of details deserve comment. Although boundaries between formations are often sharp, they are not always so. Two examples of this condition are apparent in the present illustration. One is the boundary between the Tropical Ombrophilous Submontane and Montane Forests. In some areas this boundary is clearly evident on the image whereas in other areas it is diffuse. Such diffuse boundaries, collectively termed transitions, are quite common in natural vegetation. In the present case, where the change in formation is associated with altitudinal changes, it is not surprising that transitions occur in areas of moderate regional slope while relatively abrupt boundaries are characteristic of more precipitous slopes. That a transition is occurring in this area is evident by the very gradual changes in color evident across the zone and the distinctness of the areas at opposite edges of the transition zone.

The second special boundary type is a mosaic such as that observed between the Tropical Ombrophilous Cloud Forest and Tropical Alpine Bunchgrass atop Mt. Giluwe. Here the two formations are physically discrete but are distributed in units of such a size that they cannot be shown as discrete mapping units. Rather, then, they are shown as mosaics of the formations of which the area's vegetation is composed.

The necessity for interpreting beyond color recognition is illustrated by comparison of sunlit and shadowed mountain slopes and of the two graminaceous formations. In the first case, the color shift within one formation due to directness of illumination is of the same order as the color shift between formations under constant illumination. In the second case, although colors of the Tropical Grassland and Tropical Alpine Bunchgrass are in some cases quite similar, topographic position readily establishes ecologic differences between these formations. In addition, it is quite evident from the case of the Tropical Grassland that subformational distinctions are possible. The pinker shades in this mapping unit are associated with vegetation composed of Phragmites karka (tall swamp reed) while the light blue sites are dominated by sedges and other grasses (ref. 6). In other cases, however, accuracy of subformational

distinctions remain uncertain. Although the darker red areas within the Tropical Ombrophilous Montane Forest include all areas mapped by Saunders (ref. 7) in a class identifiable as the Microphyllous Subformation, substantial areas not mapped by Saunders exhibit identical image characteristics. Without further ground survey, a positive statement regarding the feasibility of subformation mapping in the forests of this region is not possible. On Mindoro Island, Philippines, however, the Needle-leaved Subformation of the Tropical Ombrophilous Submontane Forest is visually distinctive (ref. 8; Coiner, pers. obsv.).

As plotted on this map (Figure 2), cultivated land includes land under cultivation and those areas in various stages of regrowth. Since most agriculture in the highlands of Papua New Guinea occurs as shifting cultivation, a complex mixture of apparent vegetation types is to be expected and is, in fact, observed. Areas of cultivated land are classified according to their ecological zone. That is, the map color of each cultivated area reflects the apparent formation to which the area belongs. Distinctly different crops are cultivated depending upon the ecologic potential of the area.

In addition to shifting cultivation of subsistence crops, two crops are commercially important in the major highland valley in the northeastern part of the map area. These crops are coffee and Pyrethrum. Pyrethrum flowers yield a powerful contact insecticide now widely used in sprays. These crops are well-adapted to export and therefore desirable for cultivation in a developing region because of their capacity to generate foreign exchange.

The potential utility of preparing vegetation maps on the millionth scale is illustrated by comparison of Figure 2 with Figure 3A. The latter is a LANDSAT image of a valley lying further west in Papua New Guinea. Unlike the area included in Figure 2, no ground surveys of resources have yet been completed in this western valley. Comparison of the two scenes, however, demonstrate the general similarity of vegetation formations in the two valleys. The western valley should therefore prove suitable for further expansion of these agricultural industries.

Although striking similarities are evident, certain distinctive aspects of the vegetational formations on Mindoro Island, Philippines (Figure 3B) deserve comment. Unlike the Western Highlands of Papua New Guinea, where a sword grass (Miscanthus floridulus) regrowth predominates, extensive burning of forest on Mindoro has resulted in establishment of Imperata cylindrica (cogon, kunai) Tropical Grassland (Coiner, pers. obsv.). The lower elevations and coastal areas of Mindoro support two formations not evident at the higher elevations of the New Guinea sites, the Tropical Ombrophilous Lowland Forest and Mangrove Forest. Mangroves have proven visually unique on all images examined, irrespective of adjoining vegetation types.

Many forests include both deciduous and evergreen trees in varying proportions. Deciduocity may be associated with pronounced seasonality of either precipitation or temperature. Although color differences between the evergreen and deciduous Formation Subclasses are evident during the leaf season, distinctions ensuring recognition of the Formations are enhanced by selection of images which exhibit the deciduous forest in a non-leaf or partial leaf condition. The contrast between such images is amply illustrated by comparison of Figures 3C (12 July 1973) and 3D (15 October 1972). The Great Smoky Mountains of the southeastern United States have Evergreen Needle-leaved Forest with Conical Crowns at the highest elevations (ref. 9; Williams, pers. obsv.). This formation, dominated by spruce (Picea) and fir (Abies), retains the red color of living vegetation after deciduous leaf-fall has eliminated the red color of the Montane Cold-deciduous Forest, so designated to distinguish it from drought-deciduous forests, which replaces the Evergreen Forest at lower elevations. At still lower elevations, the deciduous forests are replaced by Cold-deciduous Broad-leaved Forest with Evergreen Needle-leaved Trees, with rounded crowns in this case. This mixed forest of deciduous and pine trees of the lower elevations of the Valley of East Tennessee has now been largely replaced by cropland and other human uses except in those localities too rugged for farming. In contrast, areas ecologically suited to the occurrence of deciduous forest in this region have remained forested because they are quite unsuited to cultivation due to topography and soils.

In sharp contrast to the heavily vegetated humid regions just examined, the vegetation of the interior of Western Australia (Figure 4A) is predominantly a Semideciduous Subdesert Shrubland. The mulga (Acacia aneura) and associated shrubs are facultatively deciduous. That is, they put out leaves whenever

sufficient soil moisture is available to support growth and shed these leaves whenever the moisture supply drops below some minimum (ref. 10). This event may occur several times in a single year. At the time of image acquisition (30 November 197[illegible]), the shrubs were in leafless condition. Nevertheless, the shrublands are distinctive from the Medium-tall Grassland with a Synusia of Broad-leaved Deciduous Shrubs, although the boundary between these formations is generally gradual because the only difference between the two formations is shrub density. As the breakaways of the highlands are approached, large areas are nearly barren. Despite the inactive status of the vegetation of most of this region, formational distinctions are, then, feasible.

Representing a condition intermediate between the dense vegetation of the humid and sparse vegetation of the arid areas previously examined, northeastern Uganda illustrates conditions prevailing in a tropical savanna (ref. 11). Moisture supply varies greatly in this area, resulting in a distinctive vegetation pattern. Tropical Grassland composed of Cyperus papyrus occupies the permanent swamps of the major stream valleys. On sites having impeded drainage but not being permanently swampy, the Tropical Grassland is replaced by a Tall Grassland with a Synusia of Broad-leaved Deciduous Shrubs. Much of the area covered by this vegetation type is subjected to frequent burning, as is readily evident on this image. Because of the heavy-textured soils under this formation, which cause the drainage to be impeded, the area is not suited to cultivation and is used only for grazing cattle. Variations in degree of vigor of the vegetation of this formation are indicated by color variations. The redder the vegetation, the more vigorous the growth but the less suitable the grazing because the wetter conditions producing the vigorous growth are indicative of conditions favoring hoof-and-mouth and rinderpest, both serious cattle disease problems in Uganda (ref. 12). On better drained sites, the density of trees increases and the vegetation becomes a Tall Grassland with a Deciduous Tree Synusia Covering 10-40 Percent. The boundary between this and the preceding formation defines the northeastern limit of cultivation in Uganda. At higher elevations on the slopes of Mt. Napak savannas yield to an Evergreen Needle-leaved Woodland with Rounded Crowns dominated by Juniperus procera and Podocarpus gracilior. This woodland is quite distinctive from forests of similar composition which occur elsewhere in Uganda because of the difference between the lighter and more mottled color associated with the woodland and the darker smoother color of the forest.

Although differing in detail, certain similarities are evident between the sites in Uganda and south-central Kansas (Figure 4C). This area, surrounded by cultivated land, is characterized by Medium Tall Grassland of Sod Grasses (ref. 13, Williams, pers. obsv.). Variation of plant density due to local topographic effects in this rugged area are evident. The plants are dormant on this image because it was acquired during a dry midsummer period and the native grasses grow actively only in the presence of suitable moisture supplies. In some parts of the area sand sage (Artemisia filifolia) is a common constituent of the vegetation, transforming the formation into a Medium Tall Grassland with a Synusia of Broad-leaved Deciduous Shrubs. This formation is readily distinguished from the preceding one because of the continued active growth of the shrubs in contrast to the dormancy of the grasses. The canyons of this area contain dense stands of eastern red cedars (Juniperus virginiana) which form an Evergreen Needle-leaved Forest with Conical Crowns. Topographic position and the use of seasonal coverage permit ready distinction of the preceding formation from the Cold-deciduous Alluvial Forest composed entirely of phreatophytes on the major river floodplains. The intense infrared reflection of the forests in this area is indicative of the relatively abundant water supplies in the forested areas.

Examination of supplementary sites in Wyoming, northeast Kansas, New Jersey, the Amazon Basin, Patagonia, the Sudan, and northern Australia provide no data contravening the results discussed in this section.

DISCUSSION AND CONCLUSIONS

From the illustrated examples and other test sites examined, it has become evident that the formations of the Unesco vegetation classification can be satisfactorily distinguished on LANDSAT MSS images, especially when used as color composites and judiciously chosen as to season. The imagery

may therefore be used as a mapping base for the preparation of vegetation maps on the millionth scale. This outcome was to be expected since the chief criteria used in preparing the classification were based on density and vigor of vegetation and seasonal variations in growth behavior. It is exactly these factors which affect the return of energy to the satellite in the wavelengths to which the Multi-spectral Scanner on LANDSAT is sensitive.

The potential value of maps of this type for large-area planning is illustrated by the example from the Western Highlands of Papua New Guinea. Analysis of the imagery indicates a significant potential for the expansion of production of valuable commercial crops into an area not previously used for this purpose. Such analyses may be accomplished by either of two related methods. The first of these, illustrated by the Papua New Guinea example, uses the concept of analogous areas, interpreted from LANDSAT data through comparative analysis of vegetation and landforms. The second method relies on knowledge of the suitability of various crop plants as substitutes for natural vegetation communities. Formations may serve to effectively indicate which crop or crops have the greatest production potential in any area or to localize the areas where ground surveys are required.

One other significant value of periodic satellite coverage is clearly illustrated by Figures 4D and 4E. Human activity is resulting in continuing changes in the distributional relationships of agricultural and natural vegetation. Recently, center pivot sprinkler irrigation has expanded rapidly in southwestern Kansas. Much of this expansion has occurred in areas of Medium Tall Grassland Consisting Mainly of Sod Grasses. The two LANDSAT images indicate the marked increase in cultivation which has occurred between September 1972 and July 1974. Another formation, Medium Tall Grassland with a Synusia of Broad-leaved Deciduous Shrubs, is also present in this area. Few attempts to introduce irrigation into areas with this formation have been made and these attempts have met with limited success, indicating the general unsuitability of areas with this formation for irrigated cultivation agriculture. Utilization of repeated LANDSAT coverage then permits periodic updating of maps, both for monitoring effects of changing land use as well as the more or less striking changes attributable to droughts or other natural environmental variations.

In conclusion, this study has found LANDSAT MSS imagery suitable for the interpretation of vegetation communities at the formation level of the Unesco classification. The utility of LANDSAT data has been illustrated by a series of interpretations which produced vegetation formation identifications or maps similar to those expected from existing literature. LANDSAT data was employed to analyze natural vegetation at small scales for sites in the humid tropics, arid and semi-arid sub-tropics and temperate zones, attesting to the universal applicability of the data source when used in conjunction with the Unesco classification.

ACKNOWLEDGEMENTS

Portions of this research were conducted in the University of Kansas Space Technology Center Applications Laboratory under NASA Grant No. NGL 17-004-024.

REFERENCES

LANDSAT Images Used

Frame Number	Acqu'sition Date	Quality	Cloud Cover (%)	Area
1026-00023	18 AUG 72	Excellent	10	Papua New Guinea
1027-00081	19 AUG 72	Good	30	Papua New Guinea
1081-01462	12 OCT 72	Good	20	Mindoro,Philippines
1084-15431	15 OCT 72	Excellent	10	Eastern Tennessee
1354-15431	12 JUL 73	Good	10	Eastern Tennessee
1130-01293	30 NOV 72	Good	0	Western Australia
1194-07284	2 FEB 73	Good	0	Uganda
1194-07291	2 FEB 73	Good	0	Uganda
1257-16464	6 APR 73	Good	0	South Central Kansas
1347-16455	5 JUL 73	Excellent	0	South Central Kansas
1103-17300	3 NOV 72	Good	10	Northwest Wyoming
1399-16332	26 AUG 73	Excellent	0	Northeast Kansas
1079-15131	10 OCT 72	Excellent	0	New Jersey
1008-13475	31 JUL 72	Good	0	Amazon Basin,Brazil
1008-13481	31 JUL 72	Good	0	Amazon Basin,Brazil
1237-13314	17 MAR 73	Good	10	Patagonia,Argentina
1108-07482	8 NOV 72	Good	0	Sudan
1020-01143	12 AUG 72	Good	40	Northern Australia
1061-16570	22 SEP 72	Excellent	0	Southwest Kansas
1709-16494	2 JUL 74	Good	20	Southwest Kansas

Literature Consulted

1. Unesco. 1973. International classification and mapping of vegetation. Paris: Unesco. 93 pp.

2. Küchler, A. W., and J. M. Montoya Maquin. 1971. The Unesco classification of vegetation: some tests in the tropics. Turrialba 21:98 - 109.

3. Williams, D. L., C. King, N. E. Hardy, and J. Cihlar. 1974. Vegetation of the University of Kansas Natural History Reservation and the Nelson Environmental Study Area. Map scale 1:12,000. Lawrence, Kansas: University of Kansas Field Facilities Committee.

4. di Castri, F., and H. A. Mooney (Eds.). 1973. Mediterranean type ecosystems. New York: Springer - Verlag. 405 pp.

5. Küchler, A. W. 1967. Vegetation mapping. New York: Ronald Press. 472 pp.

6. Walker, D. 1972. Vegetation of the Lake Ipea region, New Guinea Highlands, II. Kayamanda Swamp. J. Ecol. 60: 479-504.

7. Saunders, J. C. 1965. Forest resources of the Wabag - Tari area. Map scale 1:250,000. In: General report on lands of the Wabag - Tari area, Territory of Papua and New Guinea, 1960-61. Commonwealth Scientific and Industrial Research Organization, Australia, Land Research Series No. 15: 116-124.

8. Merrit, M. L. 1908. The forests of Mindoro. U.S.D.I. Bureau of Forestry Bull. No. 8.

9. Whittaker, R. H. 1956. Vegetation of the Great Smoky Mountains. Ecol. Monog. 26: 1-80.

10. Speck, N. H. 1963. Vegetation of the Wiluna - Meekatharra area. In: General report on lands of the Wiluna - Meekatharra area, Western Australia, 1958. Commonwealth Scientific and Industrial Research Organization, Australia, Land Research Series No. 7: 143-161.

11. Langdale - Brown, I., H. A. Osmaston, and J. G. Wilson. 1964. The vegetation of Uganda and its bearing on land-use. Map scale 1:500,000. Entebbe, Uganda: The Government Printer. 159 pp.

12. Mahadevan, P., and D. J. Parsons. 1970. Livestock. In: Agriculture in Uganda. J. D. Jameson (Ed.). London: Oxford U. Press. Pp. 333-344.

13. Küchler, A. W. 1974. A new vegetation map of Kansas. Map scale 1:800,000. Ecology 55: 586-604.

14. Sochava, V. B. 1964. Rastitelnost (Vegetation). Map scale 1:60,000,000. Fiziko-Geograficheskiy Atlas Mira (Physical geographic atlas of the world). Moscow: Academy of Sciences USSR.

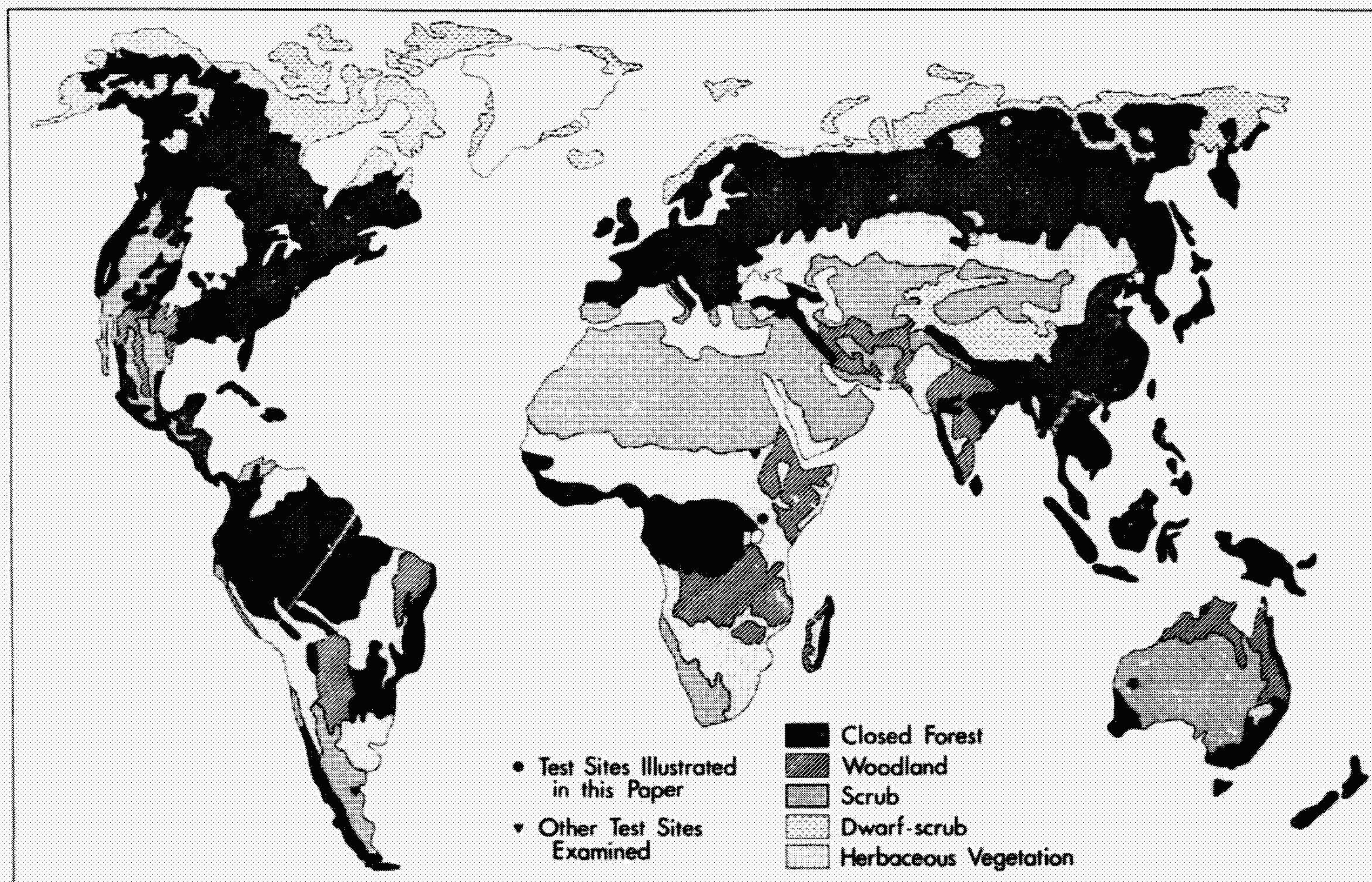


Figure 1. Location of test sites discussed in this paper with respect to the distribution of Formation Classes of natural vegetation. Vegetational data are after Sochava (ref. 14).

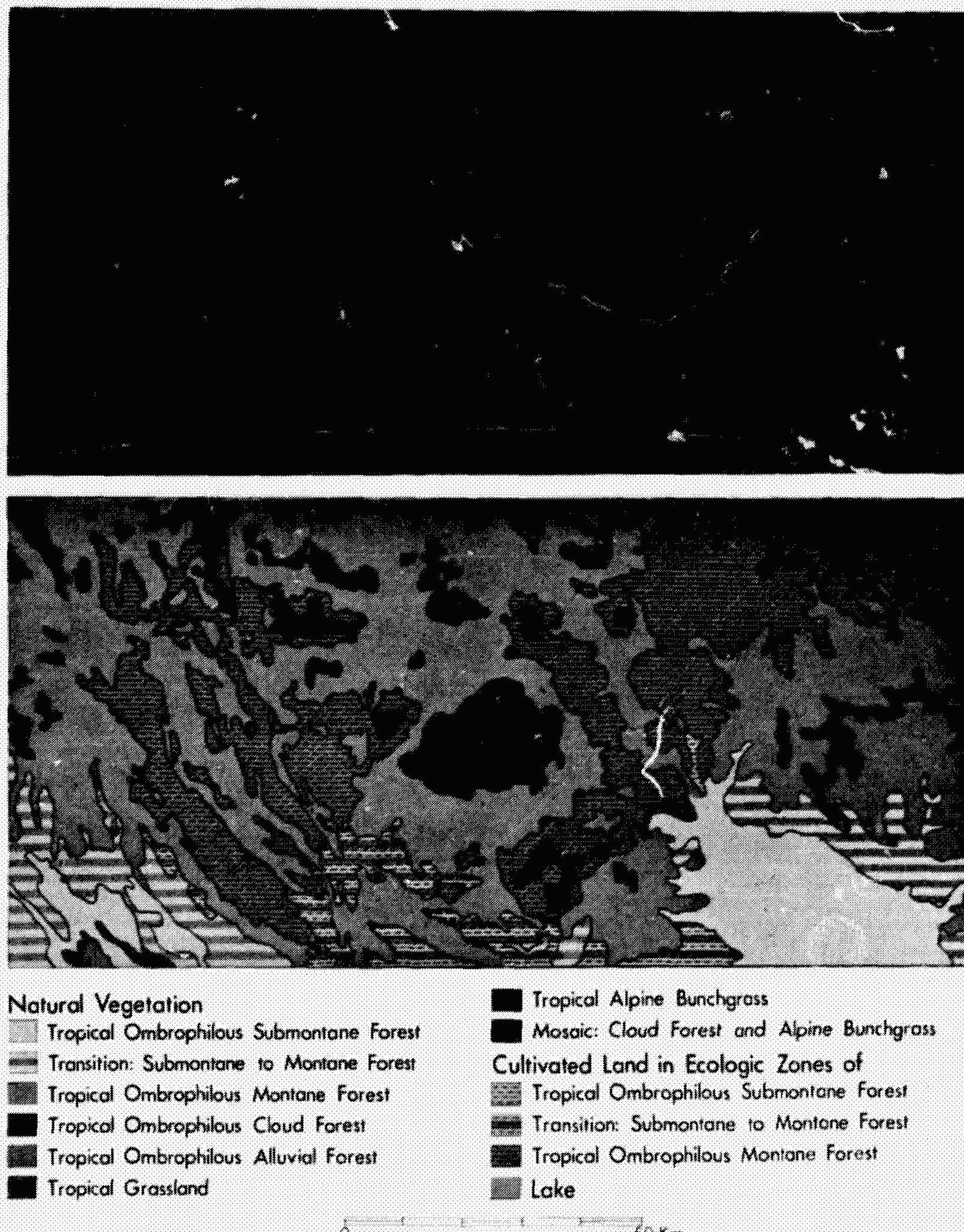


Figure 2. LANDSAT-1 image (1026-00023) of a portion of the Western Highlands of Papua New Guinea and the vegetation map prepared from this image according to the Unesco classification. It is evident by comparison of image and map that more detail is inherent in the image than may be reproduced on a map of this scale. Colors have been assigned to each cultivated area according to the apparent ecologic zone based on forest remnants and regrowth within the area.

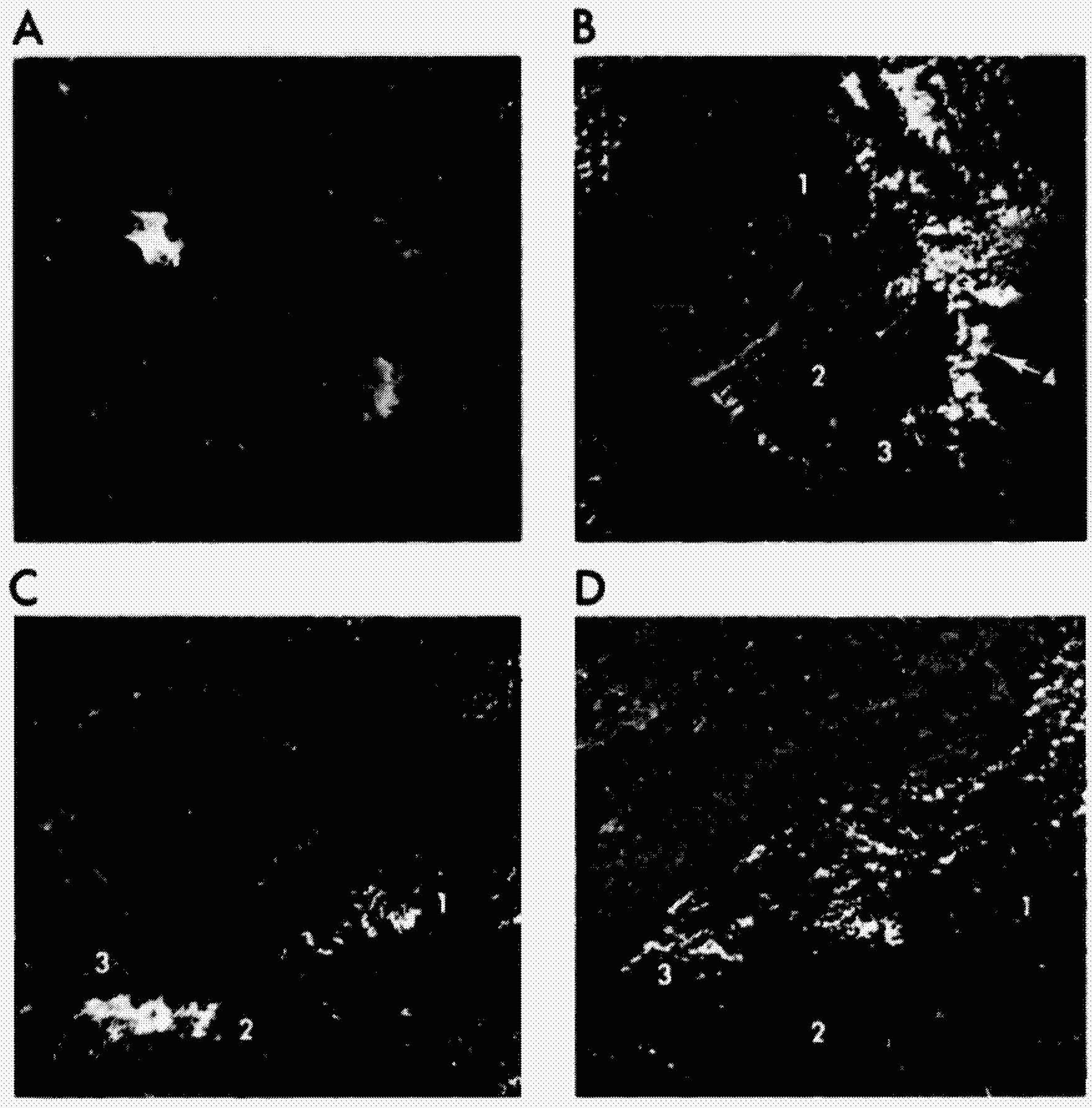


Figure 3. LANDSAT-1 images illustrative of other areas dominated by forest formations. A. Image (1027-00081) of another valley in the Western Highlands of Papua New Guinea, showing similar ecologic conditions to those on Figure 2. B. Image of Mindoro Island, Philippines (1081-014642) on which the following formations are annotated: 1) Tropical Grassland, 2) Needle-leaved evergreen subformation of the Tropical Ombrophilous Submontane Forest, 3) Tropical Ombrophilous Lowland Forest and 4) Mangrove Forest. C and D. Images showing seasonal contrast in the Great Smoky Mountains of the southeastern United States. Image C (1354-15431) was acquired 12 July 1973 while image D (1084-15431) was acquired 15 October 1972. Both frames are annotated as follows: 1) Evergreen Needle-leaved Forest with Conical Crowns, 2) Montane Cold-deciduous Forest, and 3) Cold-deciduous Broad-leaved Forest with Evergreen Needle-leaved Trees.

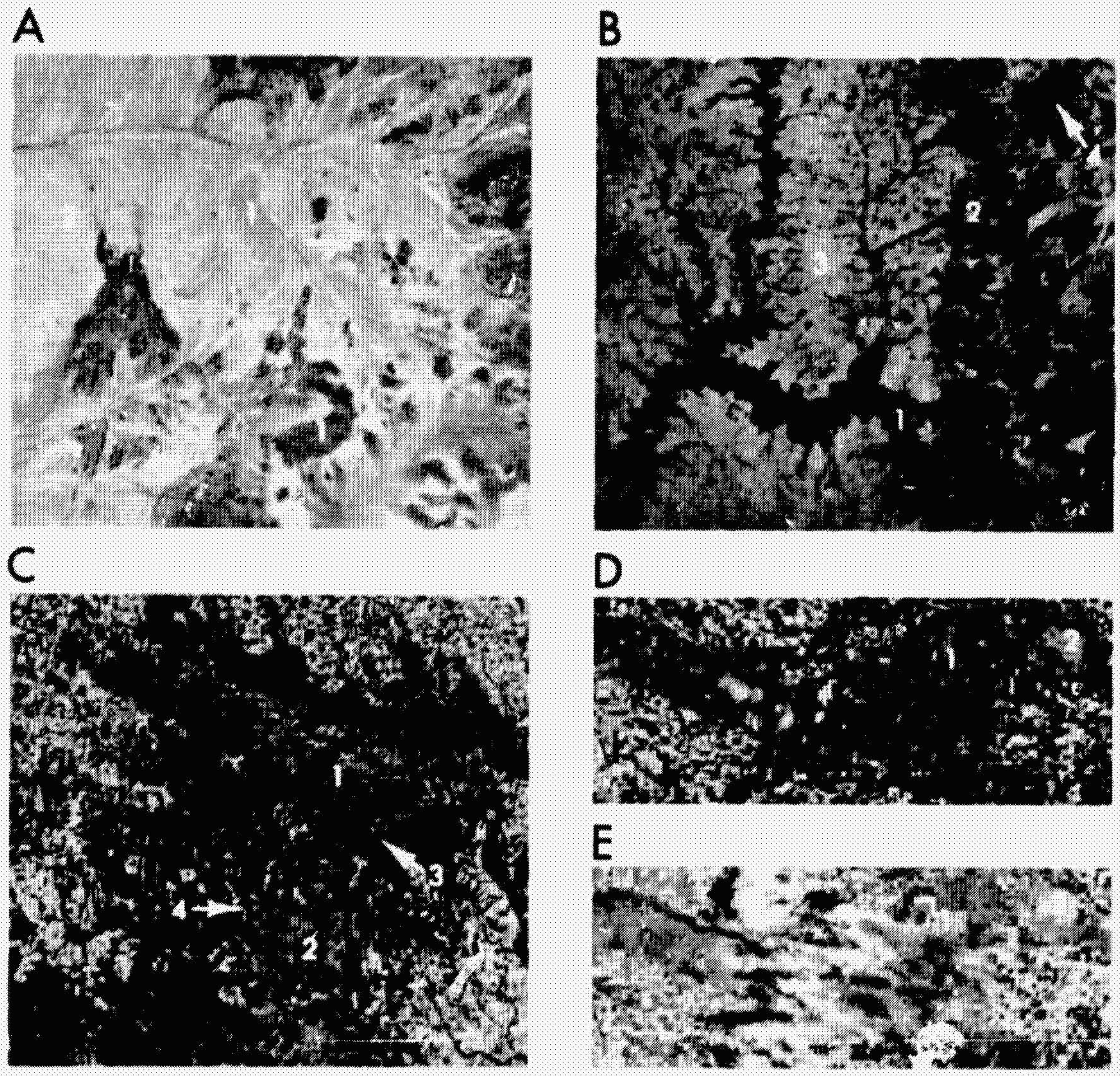


Figure 4. LANDSAT - 1 images illustrative of areas of predominantly scrub or herbaceous vegetation. A. Image (1130-01293) of interior Western Australia with the following annotations: 1) Semi-deciduous Subdesert Shrubland and 2) Medium-Tall Grassland with a Synusia of Broad-leaved Deciduous Shrubs. B. Image (1194-07284) of northeastern Uganda annotated as follows. 1) Tropical Grassland, 2) Tall Grassland with a Synusia of Broad-leaved Deciduous Shrubs, 3) Tall Grassland with a Deciduous Tree Synusia Covering 10-40 Percent and 4) Evergreen Needle-leaved Woodland with Rounded Crowns. C. Image (1347-16455) of south-central Kansas with the following types annotated: 1) Medium Tall Grassland of Sod Grasses, 2) Medium Tall Grassland with a Synusia of Broad-leaved Deciduous Shrubs, 3) Evergreen Needle-leaved Forest with Conical Crowns, and 4) Cold-deciduous Alluvial Forest. D and E. This pair of images (1061-16570 and 1709-16494) of southwestern Kansas acquired in 1972 (D) and 1974 (E) illustrate replacement of a Medium Tall Grassland by sprinkler-irrigated cropland in the areas marked 1. Areas marked 2 are Medium Tall Grassland with a Synusia of Broad-leaved Deciduous Shrubs.

LANDSAT-1 DATA, ITS USE IN A SOIL SURVEY PROGRAM A-6

By F.C. Westin and C.J. Frazee, Plant Science
Department and Remote Sensing Institute, South
Dakota State University, Brookings, South Dakota

ABSTRACT

N76-17475

There were three objectives for this study. First, to investigate the unique characteristics of LANDSAT imagery as they aid in recognizing soil survey boundaries. Second, to explore the use of LANDSAT imagery for low intensity soil surveys. And third, to investigate LANDSAT imagery as a base map for publishing thematic soils maps.

As an aid in recognizing soil boundaries, the following characteristics of LANDSAT-1 imagery have a bearing on the use of the imagery in a soil survey program. First, each scene covers such a large area that a synoptic view of soil associations is possible. An area of 3.5 million hectares can be studied where sun angle, condition of soil, stage of vegetative growth and other features are recorded at nearly the same moment. The influence of climate and vegetation, soil parent material and topography on soils can be detected. Second, the scenes are near-orthographic. Thus LANDSAT scenes join one another with very little distortion so that mosaics can be constructed. Moreover, LANDSAT scenes fit controlled base maps such as the USGS maps and thus maps showing geologic, topographic, soils, cultural and other features can be superimposed as transparencies over LANDSAT scenes. Third, since LANDSAT passes occur every 9 days, scenes can be selected for the time of the year best suited for soil survey. Moreover, the changes in vegetation and use of soils as well as the soils themselves can be observed as they change with time. Fourth, the data are recorded in four distinct parts of the electromagnetic spectrum. Since both soils and vegetation reflect differently in different parts of the electromagnetic spectrum, the use of four bands increases the chances for unique signatures for identification of vegetation and soils. Fifth, computer compatible tapes, on which the reflectances of the four bands are digitized, are useful to quantify the data of each scene.

Using many of the characteristics of LANDSAT imagery, a low intensity soil survey of Pennington County, South Dakota was completed in 1974. This study was supported in part by NASA Office of University Affairs, Grant No. 42-003-007. In South Dakota a law was passed in 1970 requiring that agricultural land be assessed for taxation according to the ability of land to produce agricultural crops or native grass. A method based on soil survey data and land sales was developed at South Dakota State University for use by assessors. Soil Survey data necessary to use this method are available for only 41 of the 67 counties in South Dakota. Low intensity inexpensive soil surveys can provide the data needed to evaluate agricultural land for the remaining counties until detailed soil surveys are completed.

LANDSAT color composite transparencies, single band transparencies and enlargement prints were interpreted to produce a soilscape map for

PRECEDING PAGE BLANK NOT FILMED

400,000 hectares. Areas of similar photographic characteristics were delineated on mylar over a color composite. The field checking was done by a resource team of soils, geology and range science specialists.

The time necessary to map and field-check the soil associations for 400,000 hectares using LANDSAT-1 imagery was four to six weeks. The total cost for this low intensity soil survey was about 2¢ per hectare. The soilscape map plus land sales data were used to prepare a land value map for the county.

In using LANDSAT imagery as a base map for publishing thematic soil maps, the first step was to prepare a mosaic. Twenty LANDSAT scenes from several late spring passes in 1973 were selected and made into a mosaic of scale 1:1,000,000. Two state LANDSAT mosaics containing soils information have now been published. They were funded in part by NASA No. 5-21771 and NASA Office of University Affairs, Grant No. 42-003-007. On the first, the soil associations are keyed to information on land sale prices from 1967-1972 and the result is a land value map on a LANDSAT mosaic. On the second, the soil associations are keyed to soil test results in South Dakota of the last 25 years for organic matter, P_2O_5, K_2O and pH. Also given for each soil association is relief and texture. Each of these publications cost about $400 for 5000 copies.

INTRODUCTION

Aerial photographs of the earth have been used as a soil survey tool since the 1930's. Since July of 1972, imagery of the earth from the Earth Resources Technology Satellite (LANDSAT) has been available. LANDSAT data are multispectral, temporal, synoptic and near orthographic. Thus they have properties not previously available in photographs taken from airplanes. Limits of LANDSAT data include lower resolution than aircraft imagery, atmospheric attenuation and, since data are taken at fixed intervals, there is no chance of avoiding cloudy or stormy weather. Since imagery is a tool of soil survey, this study was undertaken to evaluate LANDSAT imagery in a soil survey program.

The following characteristics of LANDSAT imagery have a bearing on use of the imagery in a soil survey program.

First, each scene covers such a large area that a synoptic view of soil associations is possible. An area of 3.5 million hectares can be studied where sun angle, condition of soil, stage of vegetative growth and other features are recorded at nearly the same moment. The influence of climate and vegetation, soil parent material and topography on soils can be detected.

Second, the scenes are near-orthographic. Thus LANDSAT scenes join one another with very little distortion so that mosaics can be constructed. Moreover, LANDSAT scenes fit controlled base maps such as the USGS maps. Such maps, showing geologic, topographic, soils, cultural and other features, can be superimposed as transparencies over LANDSAT scenes.

Third, since LANDSAT passes now occur every 9 days, scenes can be selected for the time of year best suited for soil survey. Soil surveyors have had very little control as to flight scheduling for acquiring aerial photographs and have had to accept photographs taken usually in midsummer when the soils are mantled with vegetation.

Fourth, the data are recorded in four distinct parts of the spectrum. Since both soils and vegetation reflect differently in different parts of the electromagnetic spectrum, the use of four bands increases the chances for unique signatures for identification of vegetation and soils.

Fifth, computer compatible tapes containing digital data relating to reflectances in each of the four spectral regions are useful to quantify the data of each scene.

Much of the literature concerning LANDSAT-1 research is available in NASA Symposium Results. Freden and Mercanti (1) have summarized the Third Symposium in three volumes. The work done in soils with LANDSAT-1 appears generally under the discipline heading "Agriculture, Forestry and Range Resources". So far, the information extracted from LANDSAT-1 data in soil survey is by direct photointerpretation or by automatic data processing techniques.

METHODS AND RESULTS

The three objectives for this study were: to investigate the unique characteristics of LANDSAT imagery as they apply to recognizing soil survey boundaries, to explore the use of LANDSAT imagery in low intensity soil surveys, and to investigate LANDSAT imagery as a base map for publishing thematic soil maps.

USE OF LANDSAT TO RECOGNIZE SOIL SURVEY BOUNDARIES

Synoptic View

Soil boundaries caused by climatic and vegetative differences usually can not be observed on conventional air photographs. No one photograph covers enough area to show evidence of these soil differences due to climate and vegetation changes since at best these boundaries are diffuse. The LANDSAT scenes, however cover an area large enough to observe climatic boundaries.

Figure 1 is of eastern South Dakota and western Minnesota along latitude 45°15'. Shown are negative prints of scale 1:500,000 of part of one scene. The tonal difference of the east and west parts is due to reflective differences of soils and vegetation. In this area the climate gradually becomes more humid toward the east. The western part of the scene receives about 21 inches of annual precipitation, while the eastern part receives about 25 inches. More small grain crops and alfalfa are grown in the drier

western part of this area, while more corn and soybeans are grown in the more humid eastern part. On June 17, 1973, the date of this scene, the small grain and alfalfa are near their peak of green growth, thus showing dark tones on this negative print of MSS-7, while the corn and soybeans do not yet cover the ground and the light tones are those of nearly bare soil. In this approximate area the line is drawn between Udoll soils on the east and Ustoll soils on the west.

While soil boundaries caused by climatic and native vegetation differences are diffuse, boundaries due to different parent materials generally are sharp. Figure 2 is a negative print at a scale of 1:500,000 of MSS-7 data from southwestern South Dakota. Loess (Area A), sand (Area B), and calcareous sandstone (Area C) soil parent materials all are apparent on the scene. Stream patterns, image tone, land-use characteristics, and land types all give clues for these separations.

Soil boundaries on the Great Plains caused by relief differences are especially apparent on imagery in areas of fine textured soils. Most of the rain falling on soils of this texture runs off because of the low soil infiltration rates. The result is a network of closely spaced drains. These drains fill with snow in the winter, thus relief differences are accentuated. Figure 3 includes negative prints of MSS-7 data of scale 1:250,000 from the Cretaceous Pierre shale area in central South Dakota. Both summer and winter scenes are shown.

Temporal Character

Figure 4 includes parts of two LANDSAT scenes from western South Dakota taken about 2 years apart. A change in use of some of the soils of the Great Plains from grass to wheat has been brought about by the increase in the price of wheat. This change in the use of soils with time can be studied with LANDSAT imagery since bare land and wheatlands are easily distinguished from grasslands.

In figure 4, two negative prints of scale 1:500,000 taken about 2 years apart, the newly cultivated land is light-toned, grassland is a medium gray tone and wheat is very dark gray.

These changes in land use can be quantified through use of the computer compatible tapes which are discussed in a later section.

Figure 5 includes MSS-7 prints of the same area of southeast South Dakota of two dates. Both scenes are negative prints of scale 1:250,000. Two principal soil associations are shown: A, a nearly level, immaturely dissected, glacial plain of silty soils formed in a thin loess cap over till; and B, a dissected plateau having rolling, deep loessial soils. The association of rolling soils(B) is easily distinguishable on the May 30 scene but is less easy to see on the August 28 scene. Vegetation, and the lack of it, which changes with time, plays a large part in distinguishing these associations. The rolling Area B is characterized by two features - considerable erosion and more close-growing crops - alfalfa, grass and small grain. This causes a mottled tone. The mostly dark areas in

these negative-print MSS-7 data are crops, and the splotches of white are the light colored, eroded soils. The flat soils of A in late May are bare or only partially covered with the recently planted corn and soybeans. Thus they appear light-toned in geometric shapes on this negative print. In the late August scene the two soil association areas appear almost uniformly dark-toned since practically all the soils are mantled with some kind of growing vegetation on this date. The May scene thus is superior to the August scene to show these soil association boundaries.

Multispectral Capabilities

One advantage in having energy recorded in four spectral bands is that unique signatures for water and for various agricultural uses of soils can be developed. Figure 6 shows 4 sections of land in western South Dakota (Sections 1-4, T106N, R77W Lyman County) as they appear in negative prints of two bands - MSS-5 in the visible spectrum and MSS-7 in the near infrared. The scale is 1:100,000. On MSS-7, fallow fields appear nearly white (have high reflectance), grass is in light gray tones, while very dark tones are of growing vegetation - milo or wheat. The type of growing vegetation is difficult to distinguish on MSS-7 in mid or late summer. However, on MSS-5, milo reflects nearly white while wheat appears dark gray at this time. Thus, using MSS-5 and 7 in combination, water, fallow, grass, milo and wheat can be separated. These are the main uses of agricultural land in this area.

A crop calendar for the region under study as well as detailed ground truth information on the date of the LANDSAT overpass are essential for land use studies.

Dark, shale-derived soils occur in central South Dakota on slopes leading down to the Missouri reservoir. These soils occur on steep slopes and in places are actively eroding. The black eroding soil in small gullies adjacent to grass-covered interfluves occurring on gentler slopes provides an energy contrast recorded on MSS-7 but not on MSS-5. Figure 7 shows MSS-5 and 7 prints of scale 1:250,000 of the same area. The eroding soils, labeled A, appear as a white fringe on the negative print of MSS-7. Thus these eroding areas can be detected on MSS-7 but not on MSS-5.

Soil surveyors are concerned about separating open water from marshland. The panchromatic film used for most soil survey base maps records energy in the visible spectrum comparable to MSS-4 and 5 of LANDSAT. Panchromatic images of emergent vegetation in marshes and open water reflect about the same on MSS-5, but open water is easily identified on MSS-7 and separable from marshland. Figure 8 is an example from glaciated eastern South Dakota. These are negative prints of scale 1:500,000. What appear to be four lakes on MSS-5 are shown to be two lakes and two marshes on MSS-7.

Near-Orthographic Character of LANDSAT Images

The geometric quality of LANDSAT MSS images is such that mosaics of adjacent images join with very little distortion. Moreover, overlays of controlled base maps fit LANDSAT images. Overlays can be prepared for geology, soils, cultural features, drainage and the like to assist users in orienting themselves on LANDSAT images for planning purposes.

Computer Compatible Tapes

Most of the work with LANDSAT data has been with photographs converted from the electronic signals received by the multispectral scanner. However, the digital data themselves are considered to have more dynamic range than can be accommodated by a photograph.

In digital processing the amount of light reflected by the smallest area recorded by the scanner on tape is given a digit. The MSS bands 4, 5 and 6 have a range of digits from 1 to 128 while MSS band 7 has a range of digits of 1 to 64. Thus the range of reflectance for the 4 bands is divided into many more categories than can be distinguished by eye from a photographic image of the scene. Each LANDSAT scene has 3,240 columns and 2,340 lines. Since each scene is 185 km square, each digit records data for about 0.45 hectares (or 1.1 acres). A histogram is prepared for each scene recording the number of times each digital value is printed, so that the acreage of each signal can be computed.

Machine processing of computer compatible tapes (CCT) is just developing. Until computer augmentation is more fully developed and generally accessible, soil surveyors still can make considerable use of the CCTs, with only simple computer software and hardware.

This is the procedure used in this study. The CCT as received from the EROS Data Center, Sioux Falls, S.D. has 2 pixels of MSS-4, 2 pixels of MSS-5, 2 pixels of MSS-6 and 2 pixels of MSS-7 printed together, followed again by 2 pixels of MSS-4, 2 of MSS-5 and so on.

Our procedure is to reformat the tape so it is compatible for use on the IBM 370/145 computer. In this procedure each band is printed separately. The first step is to get a photographic print of one band, usually 7, of an entire LANDSAT scene at a scale of 1:500,000. This is superimposed on a USGS base map of the same scale over a light table to locate the 4 corners of the LANDSAT scene on the base map. The area of study - a township or county usually - is located on the base map and lines connecting the corners of this are drawn to the left side and top of the located LANDSAT scene. Since each tape has 3,240 columns and 2,340 lines, a small area of study can be located as is shown in figure 9. On a map of 1:500,000 the LANDSAT scene measures 36.8 cm on a side. Therefore 36.8 divided into 2,340 lines indicates that there are 63.8 lines per cm. In the same manner it is determined that there are 88.2 columns per cm. The distance from the upper left corner of the LANDSAT scene is measured to the intersection of the lines connecting the 4 corners of the study area. This is converted

into columns and lines, and thus only the part of the tape encompassing the study area is printed out. The entire LANDSAT tape can be dumped but this would result in a large volume of paper and the histogram summaries would be meaningless unless the investigator wished to summarize data by LANDSAT scene. We also have found that printing every other line and column reduces printout size and although there also is some reduction in accuracy, the resolution is suitable for our agricultural applications. The reflectances of MSS-5 and MSS-7 usually are printed out and the digits are converted to alphanumeric form so one symbol utilizes one space.

The tapes printed out in this manner are not rectified. Rectification can be accomplished but requires additional computer manipulation, increasing computational time requirements. As printed out in our procedure the sections are parallelograms but not squares. Figure 10 is an example of a section of land from western South Dakota printed for MSS-5 and MSS-7 data. After locating a study area and correlating reflectances on MSS-5 and 7 with ground truth data from test sites, the combinations of reflectances on the two bands that correspond to a land use such as fallow or wheat or grass can be determined. Thus on MSS-5, figure 10, the fallow field corresponds mostly to M and N while on MSS-7 the fallow field corresponds to E and F. A second printout can be prepared for the study area assigning a unique symbol to all areas where M and N appear on MSS-5 and E and F appear on MSS-7. A histogram for the area can be prepared summarizing the separations in terms of hectares, acres or percent.

Although not sophisticated, this procedure permits inexpensive access to the quantitative data on the tapes for soil survey purposes.

USE OF LANDSAT FOR A LOW INTENSITY SOIL SURVEY

In South Dakota a law was passed in 1970 requiring that agricultural land be assessed for taxation according to the ability of land to produce agricultural crops or native grass. A method based on soil inventory data and land sales was developed by Westin et al. (2) for use by assessors in South Dakota. Soil inventory data necessary to use this method are available for 41 of the 67 counties in South Dakota. General soils information such as low intensity soil surveys which are inexpensive to make, can provide the data needed for the remaining counties until detailed soil surveys are completed.

Using many of the characteristics of LANDSAT-1 imagery, a low intensity soil survey of Pennington County, S.D. was completed in 1974. Frazee et al. (3) have prepared a detailed report on the work which was supported by the Plant Science Department and the Remote Sensing Institute of South Dakota State University and NASA under contract 42-003-007.

LANDSAT-1 color composite transparencies, single band transparencies and enlargement prints were interpreted to produce a soilscape[1] map for

[1] The term "soilscape" is a contraction of "soil landscape" described in Buol, Hole and McCracken in Soil Genesis, p. 300 as the assemblage of soil bodies on a land surface in a particular landscape.

400,000 hectares. Areas of similar photographic characteristics were delineated on mylar over a color composite using a light table and a three-power magnifying glass. The field checking was done by a resource team of soil, geology and range science specialists.

The color composite transparency was adequate for locating most of the boundaries between soilscape areas. The time necessary to map and field check the general soils for 400,000 hectares using LANDSAT-1 imagery was 4 to 6 weeks. The soilscape map and land sales data were used to prepare a land value map for the portion of Pennington County east of the Black Hills.

The color composite transparencies were most useful for interpretation of boundaries between soilscape areas. The interaction between the individual bands provided useful clues for interpretations. Most of the boundaries were delineated very well on the LANDSAT-1 imagery. Areas such as flood plains which were too small to delineate using the color composite transparency at a scale of 1:1,000,000 were mapped using the 1:250,000 enlargement prints.

The map with major soil boundaries interpreted in the office by photo-interpretation of the color composite transparencies, single band positive transparencies, and enlargement prints is shown in part in figure 11. Table 1 is the legend for this preliminary interpretation. This map (figure 11) was transferred to the USGS 1:250,000 scale topographic map for field checking. Each area delineated was visited and the soil, vegetation and geologic materials were described as well as the surface features responsible for the reflectance patterns apparent on the LANDSAT imagery.

Examination of the LANDSAT imagery in the field indicated several additional boundaries. These were delineated and the final map prepared (figure 12). Table 2 is the complete legend. Figure 13 is a line map enlargement of figure 12. Figure 14 is the current soil association map of Pennington County by Westin and Bannister (4). It can be noted that more soil areas are delineated on the soilscape map (figure 12) than on the current soil association map.

The major differences between the two maps are in the areas with soils formed from the Fox Hills Formation, the White River Sediments and terraces overlying the Pierre Shale. Area No. 32 on the Soils Association map, figure 14, the Ralph-Cabbart-Regent Association, was divided into 4 areas using slope and land use data. The Badlands area labeled under 69 was divided into three segments using color and color pattern interpretations. The terraces, Caputa Association, 36, were separated into three parts.

The features or characteristics observable on the LANDSAT color composite transparency which were used for interpreting the soilscape boundaries were tone, color, land use patterns and drainage patterns.

The soilscape map of Pennington County was interpreted to give the Director of Equalization general guidelines for land evaluation. This is shown in figure 15. In this process a crop and grass yield rating was calculated for each soilscape and related to sales figures from 1967-1973 furnished by the Director of Equalization.

The cost for this low intensity soil survey was roughly 2¢ per hectare. The LANDSAT imagery for the area of the county covered cost $100, and travel was $100. The office interpretation, the field check and the final drafting took about 36 man days.

USE OF LANDSAT IMAGERY AS A BASE MAP FOR PUBLISHING SOIL INFORMATION

Since LANDSAT scenes are near orthographic, adjacent images join with very little distortion. Twenty LANDSAT-1 scenes from several late spring passes in 1973 were selected and made into a mosaic of scale 1:1,000,000 by Jack Smith, Photographic Technician at the SDSU Remote Sensing Institute. It would be unusual for all LANDSAT scenes in a single pass to be cloud free and so it was necessary to utilize several passes. Some scenes were joined which differed in date by 18 days and although this was undesirable, it could not be avoided. It would take about 30,000 conventional air photos to cover South Dakota. The expense of constructing a state mosaic from conventional air photos would be impractical.

For this mosaic, negative prints of MSS-7 were used. For our materials, negative prints were one generation closer to the original and hence were sharper than positives. Band 7 was selected because all water bodies are well defined, and bare soil contrasts sharply with cultivated land and grass and trees. A LANDSAT photographic background for soil related information greatly enhances its use since much can be deduced about hydrology and land use.

Two state LANDSAT mosaics have been published, Westin (5) (AES No. 5), and Westin (6) (AES No. 7). AES No. 5 shows 53 soil associations to which are keyed information on land sale prices from 1967-1972, general agricultural use, relief, soil texture and soil parent material. A portion of AES No. 5 is shown in figure 16. AES No. 7 has 30 soil associations to which are keyed soil test results since the 1950's for organic matter, P_2O_5, K_2O and pH. Also given for each soil association is relief and texture. Small maps of the state printed in the margins show annual precipitation and temperature, elevation, soil parent material, growing degree days, physical divisions, and approximate farm size. Each of these publications cost about $400 for 5000 copies.

AES No. 5 was intended for users interested in land prices, while AES No. 7 was intended for users interested in the nutrient status of their soils and to assist in planning herbicide rates of application which depend on the soil texture, organic matter content and pH. In both pulications, the soils data presented are more meaningful because the LANDSAT photographic image permits the user to see the general use of the soils.

AES No. 5 was funded in part by NASA 5-21774 and AES No. 7 by NASA Office of University Affairs, Grant No. 42-003-007.

South Dakota Agricultural Experiment Station Journal Article Number 1342

REFERENCES

1. Freden, S.C. and E.P. Mercanti. 1974. Third ERTS Resources Technology Satellite Symposium, Vol. I, II, III. Scientific and Technical Information Office, NASA, Washington, D.C.

2. Westin, Frederick C., M. Stout Jr., D.L. Bannister and C.J. Frazee. 1974. Soil Surveys for Land Evaluation. Assessors Journal, Vol. 9 No. 3. International Association of Assessing Officers, 1313 E. 60th Street, Chicago, Ill. 60637.

3. Frazee, C.J., P.H. Rahn, F.C. Westin and V.I. Myers. 1974. Use of ERTS-1 Imagery for Land Evaluation in Pennington County, S.D. South Dakota Agricultural Experiment Station Journal, Series No. 1276, Brookings, S.D. 57006.

4. Westin, F.C. and D.L. Bannister. 1971. Soil Associations of South Dakota (Map). AES Info Series No. 3. Agricultural Experiment Station, South Dakota State University, Brookings, S.D. and Soil Conservation Service, Huron, S.D.

5. Westin, F.C. ERTS Mosaic of South Dakota Showing Soil Association Value Areas. AES Info Series No. 5. Agricultural Experiment Station and Remote Sensing Institute, SDSU-RSI 73-17, Brookings, S.D. 57006.

6. Westin, F.C. Soil Texture, Soil Slope and Soil Test Results on an ERTS Mosaic of South Dakota. 1974. AES Info Series No. 7. Agricultural Experiment Station and Remote Sensing Institute SDSU-RSI 74-3. Brookings, S.D. 57006.

Table 1. Legend for Preliminary Interpretation.

A. Soilscapes from White River Sediments
A1 -- Badland walls and basins, steep
A2 -- Badland uplands, nearly level to undulating
B. Soilscapes from Pierre Shale
B1 -- Shale Breaks, steep
B2 -- Shale Plains, gently rolling
B3 -- Shale Plains, undulating
B4 -- Terraces, nearly level
B5 -- Alluvium
C. Soilscapes from Fox Hills Formation
C1 -- Sandstone Breaks, Steep
C2 -- Sandstone Uplands, gently rolling
C3 -- Sandstone Uplands, nearly level
D. Soilscapes from Black Hills Footslope
D -- Uplands, gently rolling

Table 2. Soilscapes of Eastern Pennington County

Unit	Land Form	Geologic Material	Soil	Range Site	Land Use	LCS*	Ground Water**
A	Soilscapes from White River Sediments						
A1	Hilly to very steep barren badlands	Siltstone and shale	None	None	Non-Agricultural	8s	None to Poor
A2	Undulating to gently rolling uplands	0-5' of terrace alluvium over White River Sediments	Shallow to Moderately Deep Clayey Soils	Clayey-Shallow	Rangeland	4e-6s	Poor
A3	Nearly level to undulating badland basins	Clayey alluvial sediments	Shallow to Moderately Deep Clayey Soils	Clayey-Shallow	Rangeland	4e-6s	Poor
A4	Nearly level to undulating table lands	5-20' of terrace alluvium and aeolian deposits over White River Sediments	Deep Silty and Loamy Soils	Silty-Sandy	Cropland Rangeland	3c-3e-4e	Fair
B	Soilscapes from Pierre Shale						
B1	Steep shale breaks	Pierre Shale	Shallow to Moderately Deep Clayey Soils and Shaleland	Shallow	Rangeland	7s-6e-8s	None to Poor
B2	Undulating to rolling sideslopes	Colluvium from Pierre Shale	Shallow, Moderately Deep to Deep Clayey Soils	Clayey	Rangeland	6e-4e-6s	Poor
B3	Undulating to gently rolling plains	Colluvium from Fox Hills Sandstone and Pierre Shale	Deep Clayey and Thin Claypan Soils	Clayey-Claypan	Rangeland	4e-6s	Fair to Good
B4	Undulating plains	Thick colluvium from Pierre Shale	Moderately Deep to Deep Clayey Soils	Clayey	Cropland	4e	Fair

Table 2. Continued

Unit	Land Form	Geologic Material	Soil	Range Site	Land Use	LCS*	Ground Water**
B5	Undulating to rolling dissected terraces	5-10' of terrace alluvium over Pierre Shale	Moderately Deep to Deep Loamy Soils	Clayey-Thin Upland	Rangeland	4e-6e	Fair
B6	Undulating to gently rolling terrace remnants	5-10' of terrace alluvium over Pierre Shale or White River Sediments	Deep Loamy Soils	Clayey	Rangeland-Cropland	3e-4e	Fair
B7	Nearly level to undulating terrace remnants	5-50' of terrace alluvium over Pierre Shale	Deep Loamy Soils	Clayey	Cropland	3c-3e	Fair
B8	Nearly level terraces	5-20' of terrace alluvium over Pierre Shale	Deep Silty and Loamy Soils	Silty-Clayey	Cropland	3c	Fair to Good
B9	Nearly level terraces	0-5' of terrace alluvium over Pierre Shale	Moderately Deep Loamy Soils	Silty	Rangeland	4s	Fair to Good
C	Soilscapes from Fox Hills Formation						
C1	Hilly to steep breaks	Fox Hills Sandstone and Shale	Shallow to Moderately Deep Loamy Soils	Shallow	Rangeland	7s	Fair
C2	Rolling uplands	Colluvium from Fox Hills Sandstone and Shale	Shallow, Moderately Deep to Deep Silty Soils	Silty-Shallow	Rangeland	6e-6s	Fair to Good
C3	Undulating to Gently rolling uplands	Colluvium from Fox Hills Sandstone and Shale	Deep Silty Soils	Silty	Cropland	3e-4e	Fair to Good
C4	Nearly level to undulating uplands	Colluvium from Fox Hills Sandstone and Shale	Deep Silty Soils	Silty	Cropland	3e-3c	Fair to Good

C-2

Table 2. Continued

Unit	Land Form	Geologic Material	Soil	Range Site	Land Use	LCS*	Ground Water**
D	Flood Plains						
D1	Flood plains of Cheyenne and White Rivers	Sands and fine textured alluvium	Deep Clayey and Thin Sandy Soils	Clayey-Overflow	Rangeland-Hayland	4s-4e-6w	Excellent
D2	Flood plains of Rapid, Box Elder, and Spring Creeks	Medium textured alluvium	Deep Silty Clay Loam Soils	Overflow	Hayland	3c-6w	Excellent
E	Soilscapes from Black Hills Footslopes						
E1	Rolling uplands	Colluvium from Carlisle, Greenhorn and Niobrara Formations	Moderately Deep Clayey and Loamy Soils	Thin Upland-Clayey	Rangeland	6e-4e	Fair to Poor
E2	Rolling uplands	Clayey colluvium and bedrock from Graneros Group	Shallow to Moderately Deep Clayey Soils	Shallow-Clayey	Rangeland	6s-6e	Fair to Poor

* LCS Land Capability Subclass
** Potential for development of household wells

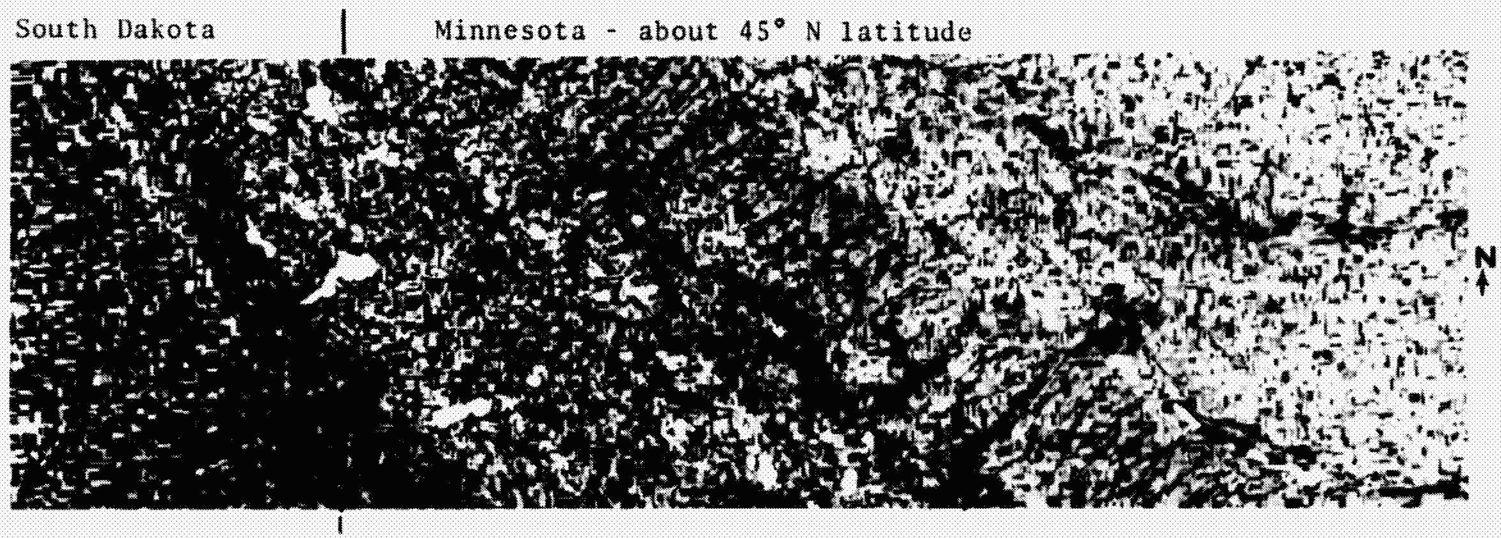


Figure 1. Diffuse boundary due to climatic change separating soil associations. LANDSAT scene of 17 June 73 1329-16440-7 Scale 1:500,000. Soils at eastern edge of scene (on the right) receive more moisture and thus are used primarily for corn and soybeans, neither of which mask the soil surface at this date. These lands thus have low reflectance and gray tones on this negative print. Soils at the western edge of the scene receive less moisture hence are used more extensively for crops like small grains which require less moisture. On this June date these small grains are reflecting strongly in the infrared and thus have dark tones on this negative print.

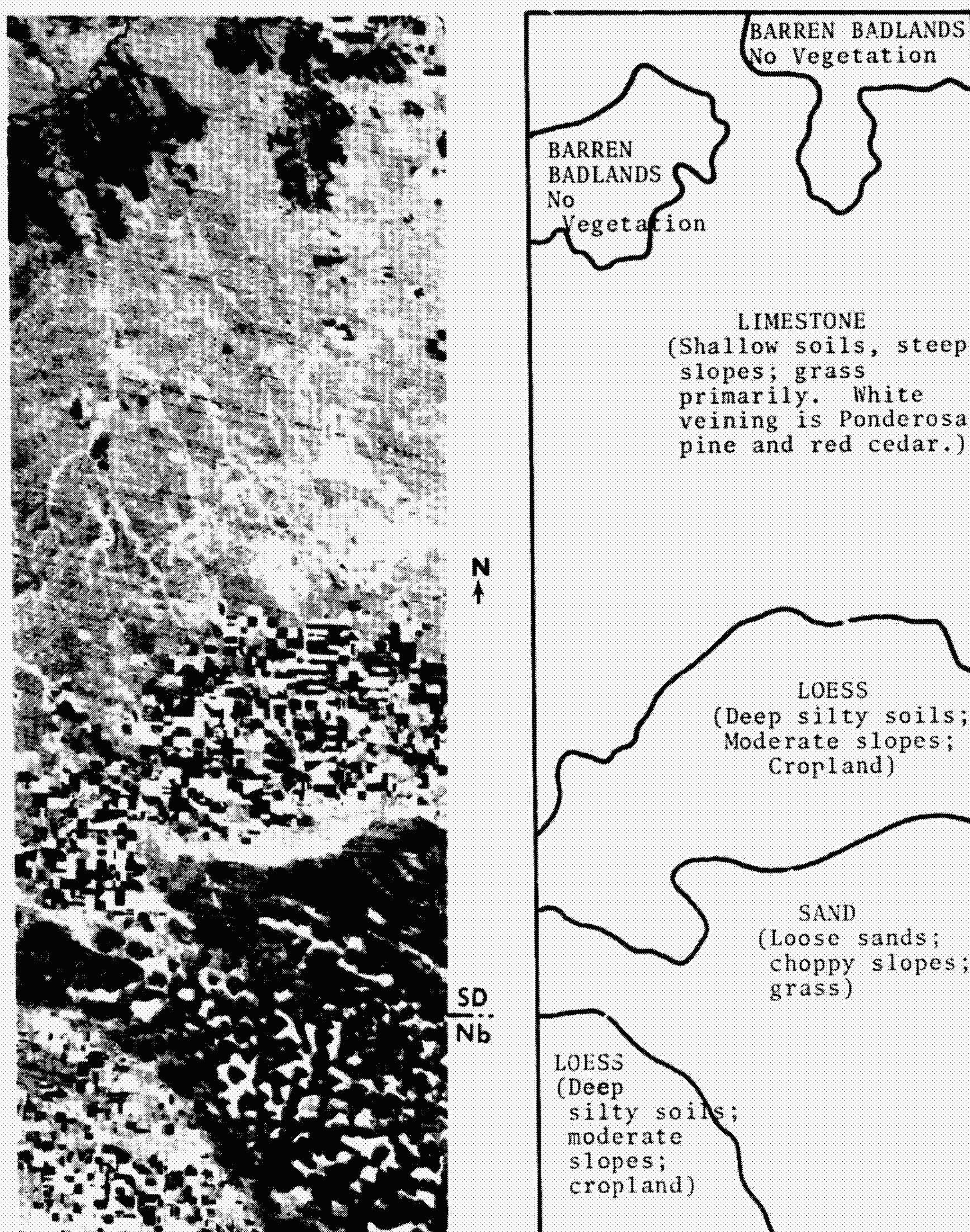


Figure 2. Sharp boundaries due to soil parent material differences, Southwest South Dakota. LANDSAT scene of 3 June 73, 1315-17073-5 Scale 1:500,000. Negative print.

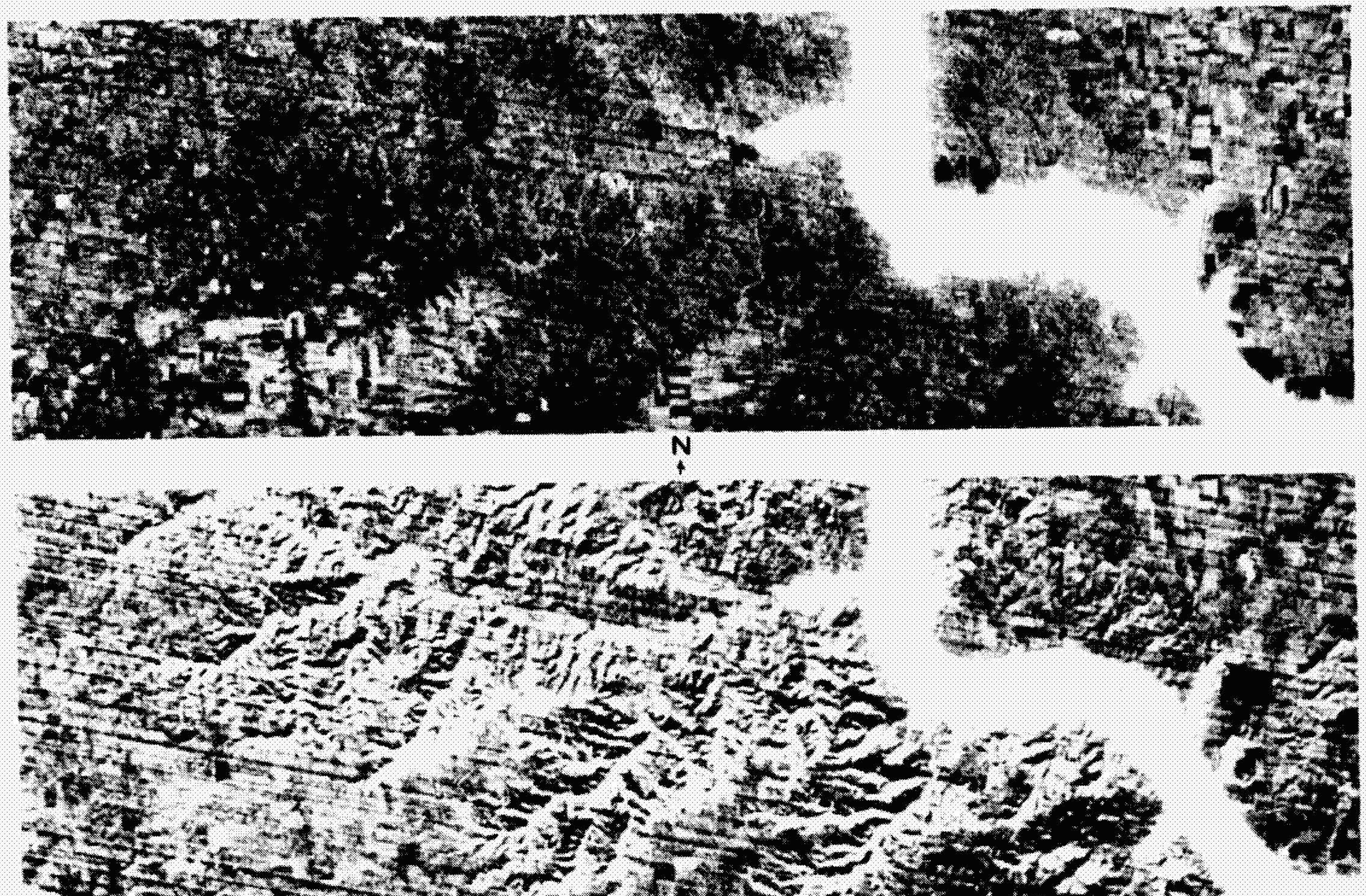
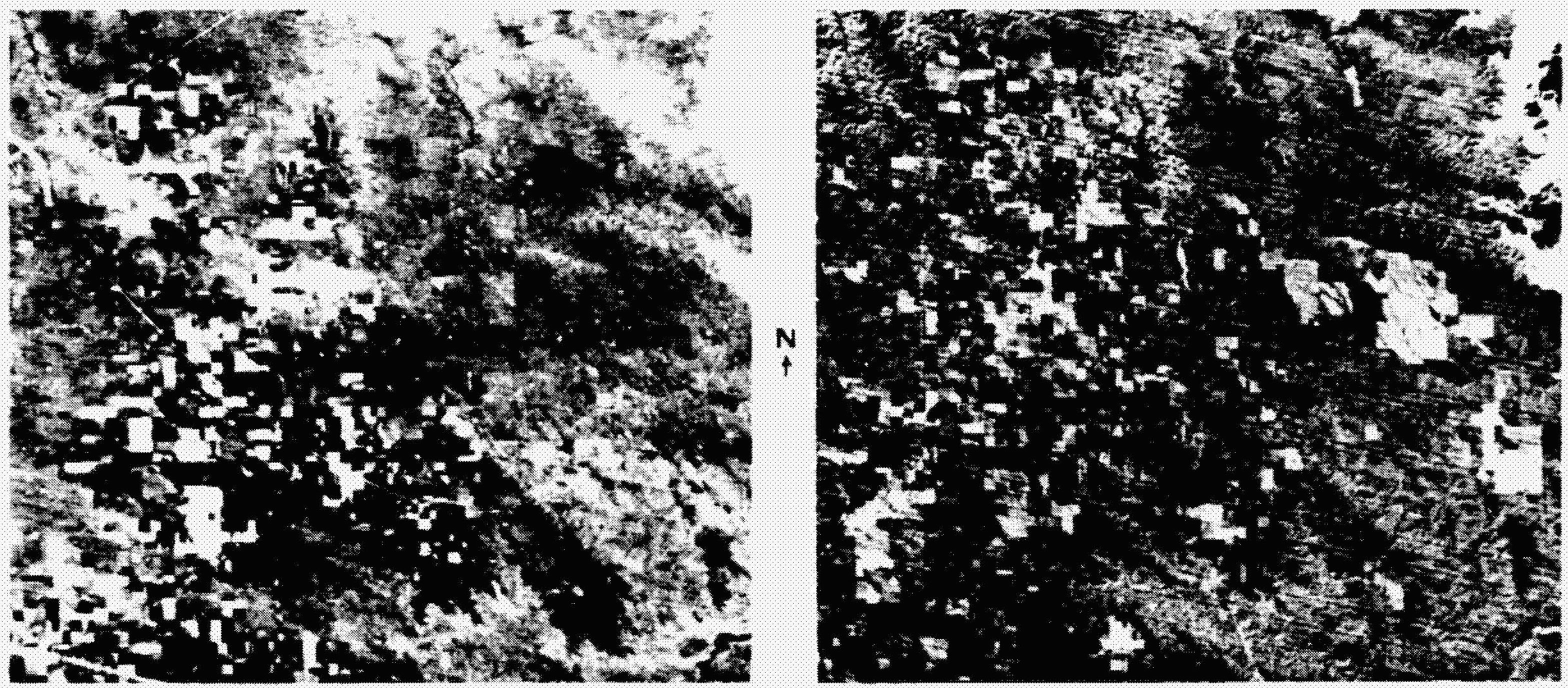


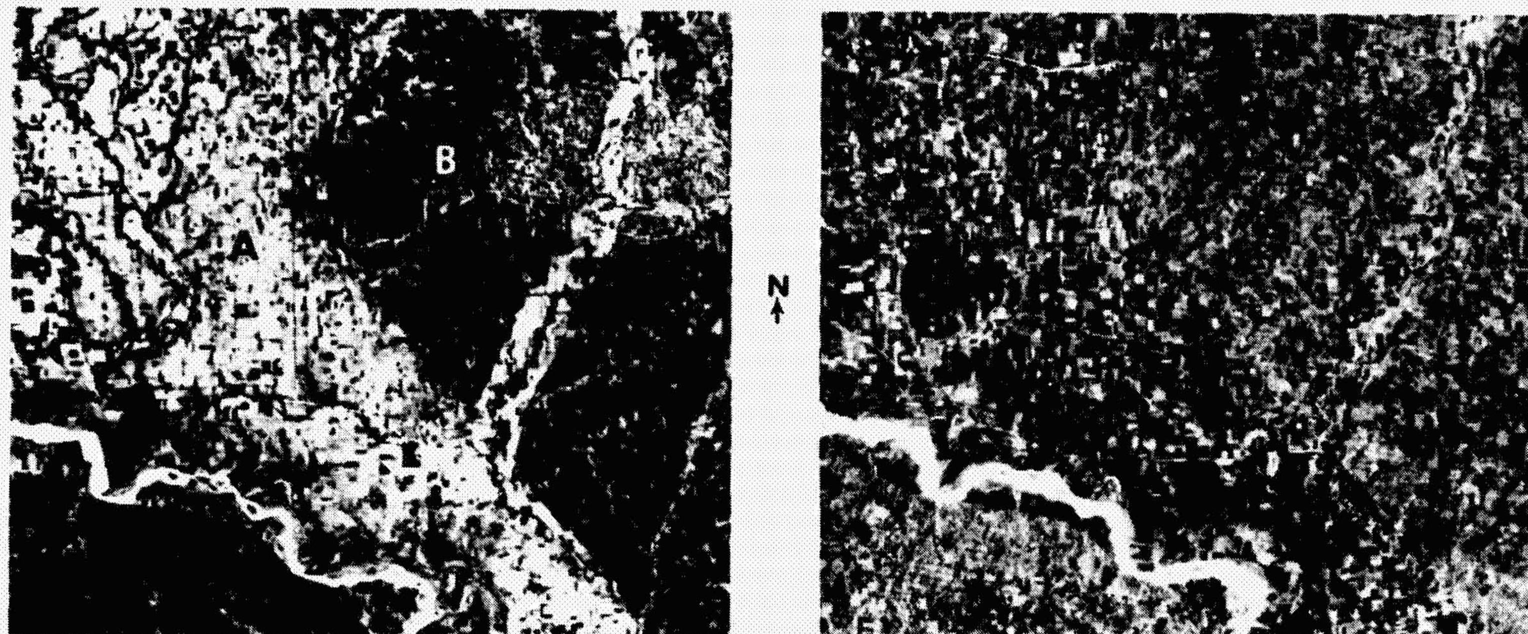
Figure 3. Soil Association boundaries caused by topography differences as seen during June and December. The top scene is of 19 June 74 1726-16414-7. The lower of 10 Dec 74 1870-16364-7, on both the scale is 1:250,000 and both are from along the Missouri River Reservoir in Central South Dakota above Fort Randall Dam. Snow etches the drainageways and assists in topographic delineation.



5 Sept 72 1044-17004-7
Scale 1:500,000

24 Nov 74 1854-16483-7
Scale 1:500,000

Figure 4. Temporal changes in use of soils. Both scenes are negative prints of the same area just west of the Oahe Reservoir in central South Dakota. The reservoir is visible on the northeast corner of the scene. The light gray geometric areas are fallow fields, the dark ones mostly winter wheat or alfalfa. The intermediate gray tones are grass and the small white specks especially noticeable in the 1972 scene are stock ponds. Note the number and size of the new fields on the 1974 scene, some in fallow and some in winter wheat. These clay soils in the Great Plains area of South Dakota generally are not cropped unless slopes are nearly level. The network of drains in the newly cultivated areas indicate they occur on sloping areas subject to erosion.



30 May 73 1311-16444-7
Scale 1:250,000

28 Aug 73 1401-16433-7
Scale 1:250,000

Figure 5. Temporal change useful in identifying soil associations. Both scenes are negative prints of the same area in southeast South Dakota. The Missouri River is the large river in the lower left. The Big Sioux River is the stream on the right part of the scene. On the May scene the flat soils (A) were recently planted to corn and soybeans but still reflect mainly bare soil and are light gray and sharply separated on MSS-7 from the rolling and sloping areas (B) used primarily for small grains, grass and other close growing crops. In August the separation of the soil associations boundaries is less distinct since nearly all of the area is vegetated and reflecting strongly on MSS-7. Thus, for detecting soil boundaries in this area the May scene offers a distinct advantage.

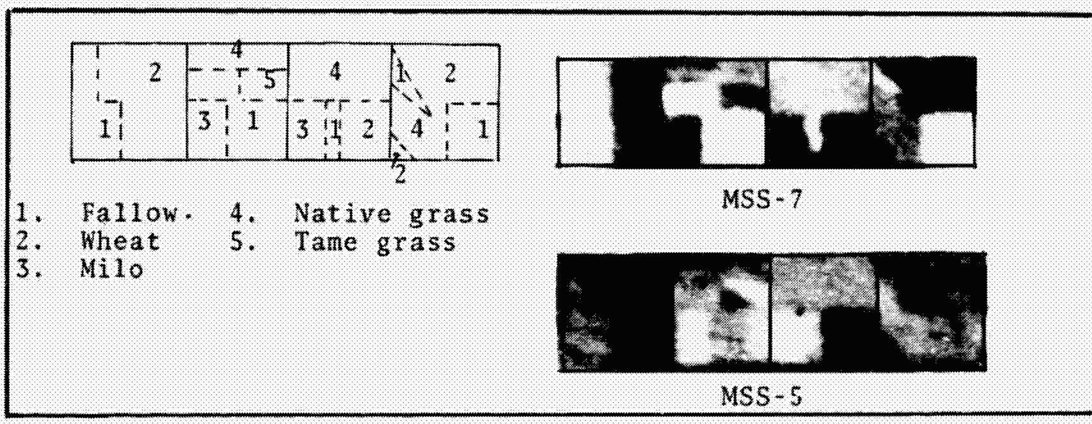


Figure 6. Multispectral differences of the same land use. Negative print of sections 1-4, T106N, R77W, Lyman County, South Central South Dakota. 17 Aug 72 1025-16551.

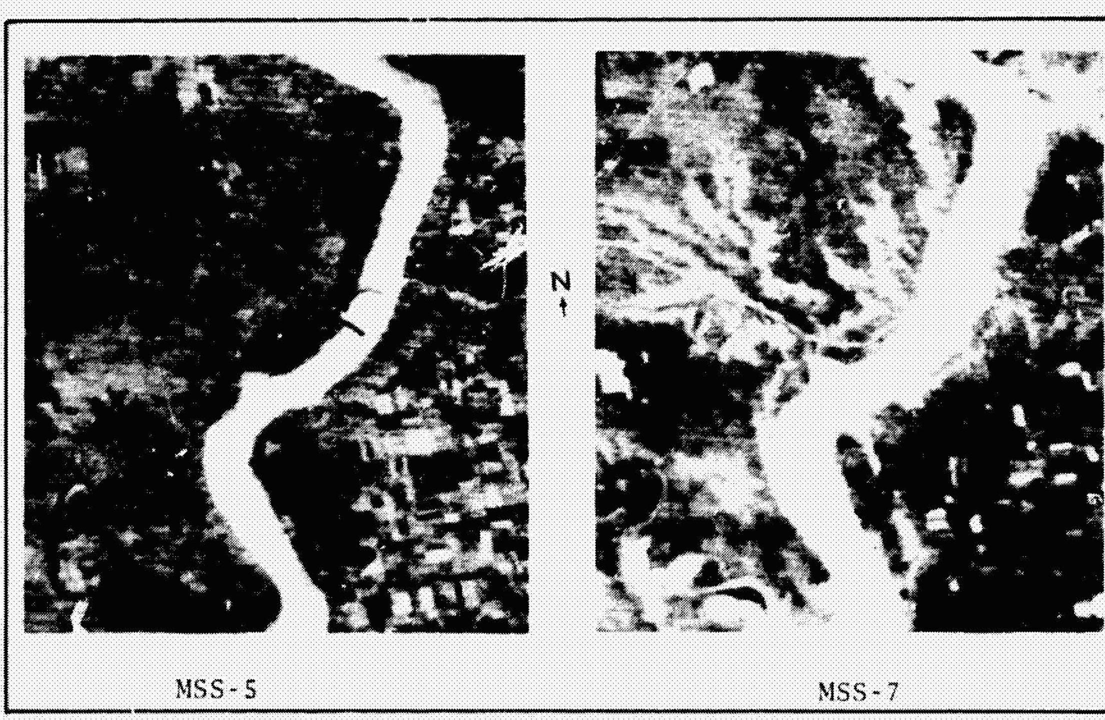


Figure 7. Multispectral differences of the appearance of erosion above the Missouri River Reservoir in south central South Dakota. The white fringe on MSS-7 identified by an arrow is bare eroding soil. Negative prints of 17 Aug 72 1025-16551.

MSS-5 MSS-7

Figure 8. Multispectral differences in the appearance of lakes (L) and marshes (M) on LANDSAT scene of 21 Sept 72 1060-16491. Scale 1:250,000.

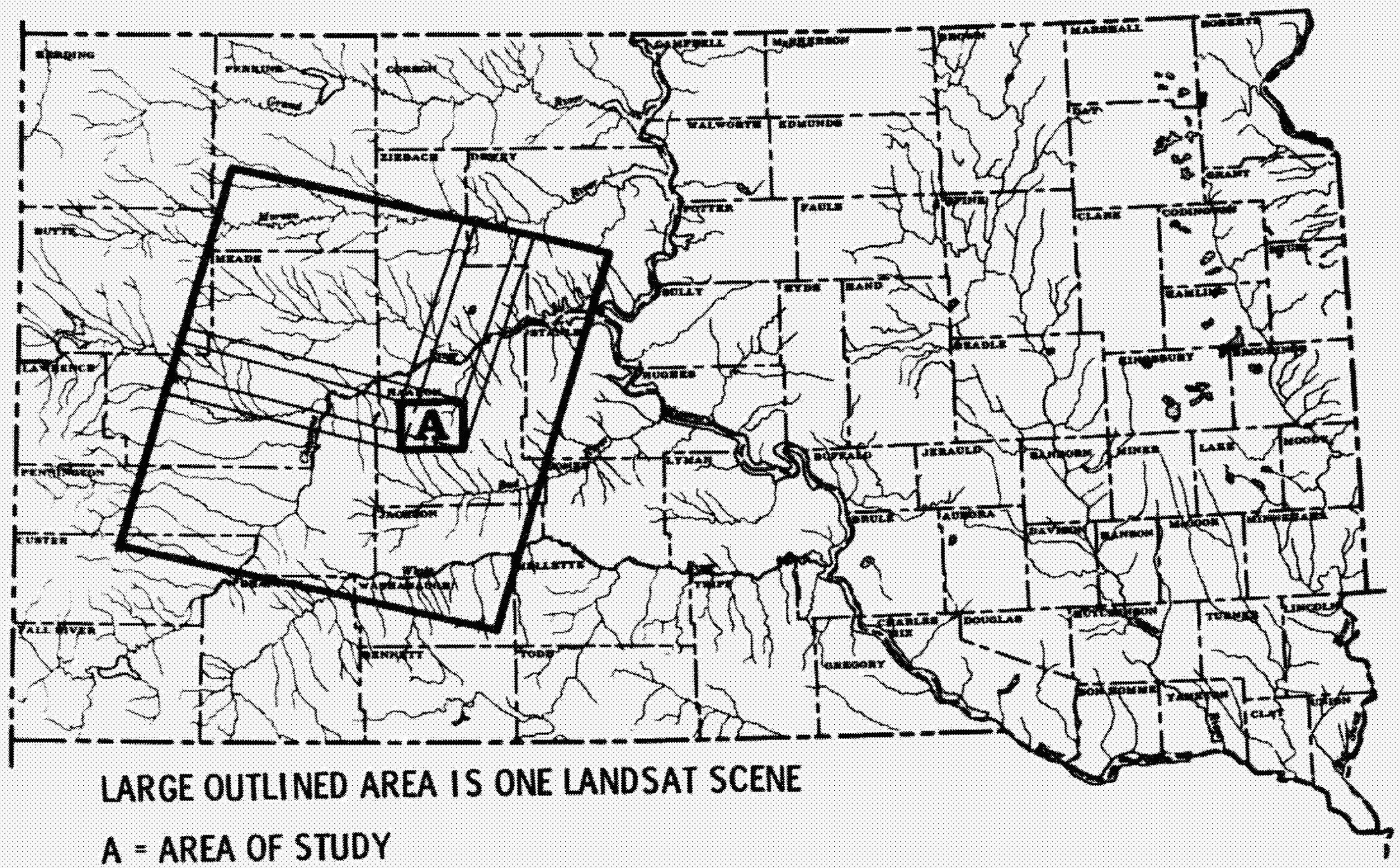


Figure 9. Location of a LANDSAT scene in South Dakota.

Figure 10.

LANDSAT-1 19 Aug 72
COMPUTER COMPATIBLE TAPE, BANDS 5 AND 7
SECTION 32, T37N, R26W, BENNETT COUNTY, S.D.

```
       BAND 5                        BAND 7

     ONONNRRPNN                   NQJIJIIHHG
  RPMIHNNOMNQQNM              JKIIIKNQJIJIIHHG
QIIJJGFFLNOPMRQQM             JKJKKQSRLJJJIHHJ
PKJJKIFGJOPQQRRON             JJIKJMRQMIIIJHHSE
 NIJJGFIGLNMJNQQQM            IIKJLPRQRKJJIJHHGF
 NMMMFFGGJNNPKKRPM             FKKKTSRQNIIJJIJJF
 ONSFIKLNOSSRSQMKMN            GILLPMIFFIJJJIIHF
  NLMMMLNMPSRRQPROK             GGFFFEFFIJJJJKJH
  NMNNMLMMNQTQTQRRK             GNFFFEFFGKKKJJJKI
  PONNNMNNNONNNPOQK               IFFFFFEFIJIJJIJI
   ONNMMMMMMLLKJKKML              IIFFFFFFGIJLNCKK
   NONNLLMOJJJKJNLKK                IEEGHIHNNNONNM
   OPWPPPOQM                         KIIHII
```

One-quarter section (160 acres) of fallow outlined.

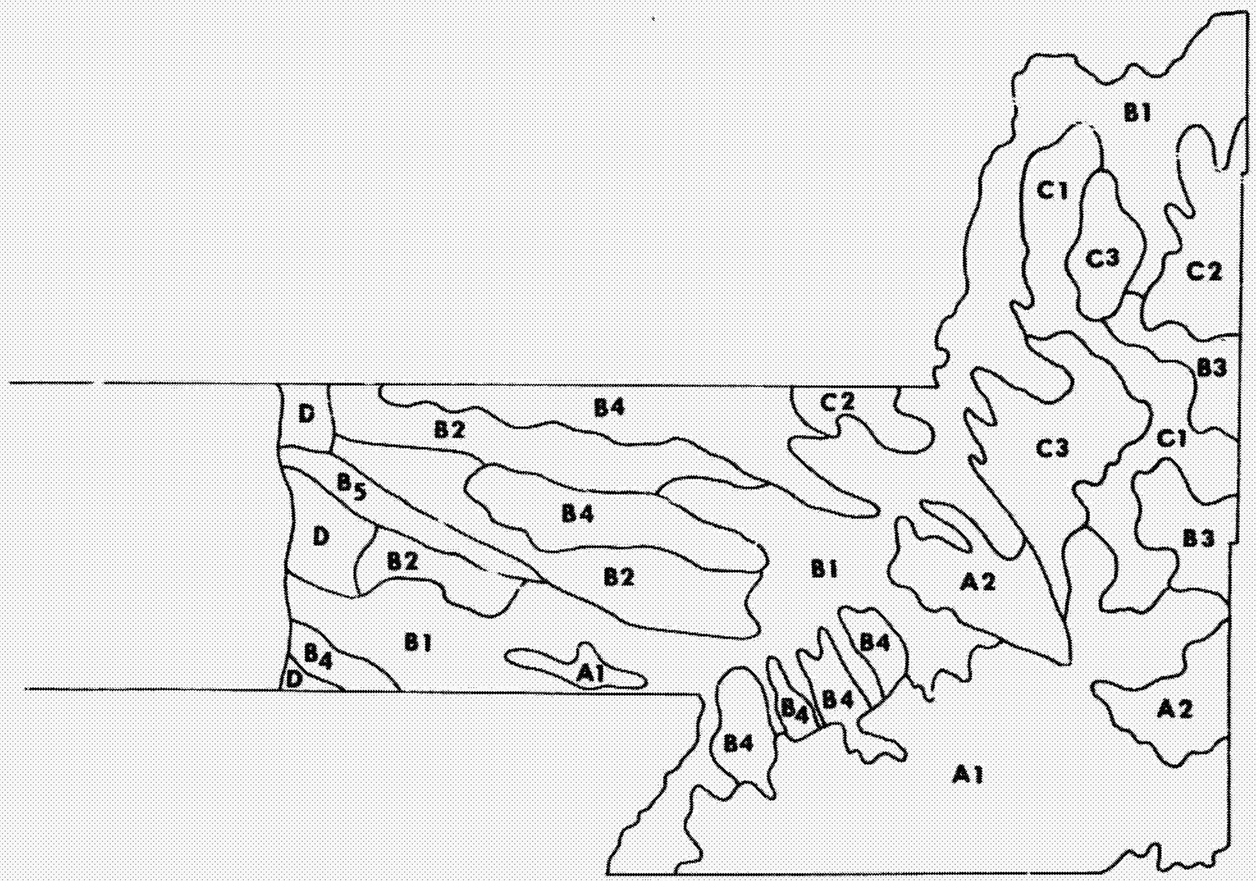


Figure 11. Preliminary interpretation of LANDSAT-1 imagery of eastern Pennington County, South Dakota.

Figure 12. LANDSAT color composite of Pennington County, South Dakota with soilscape map on Plains portion. Scale about 1:1,000,000. The western third, roughly, of the county is in the Black Hills and out of the study area. The legend for the map is table 2. Figure 13 is an enlarged line drawing of this map.

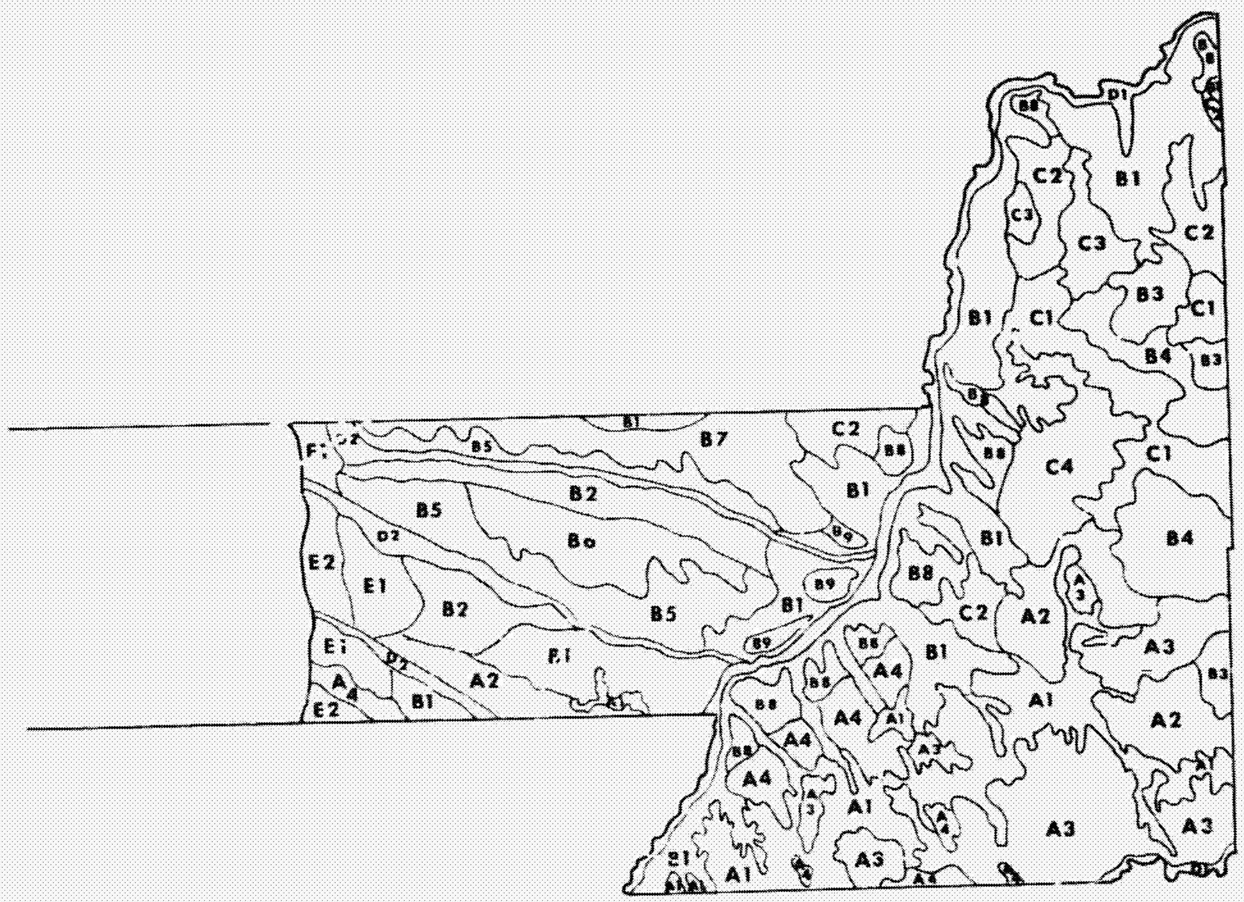


Figure 13. Soilscapes of eastern Pennington County

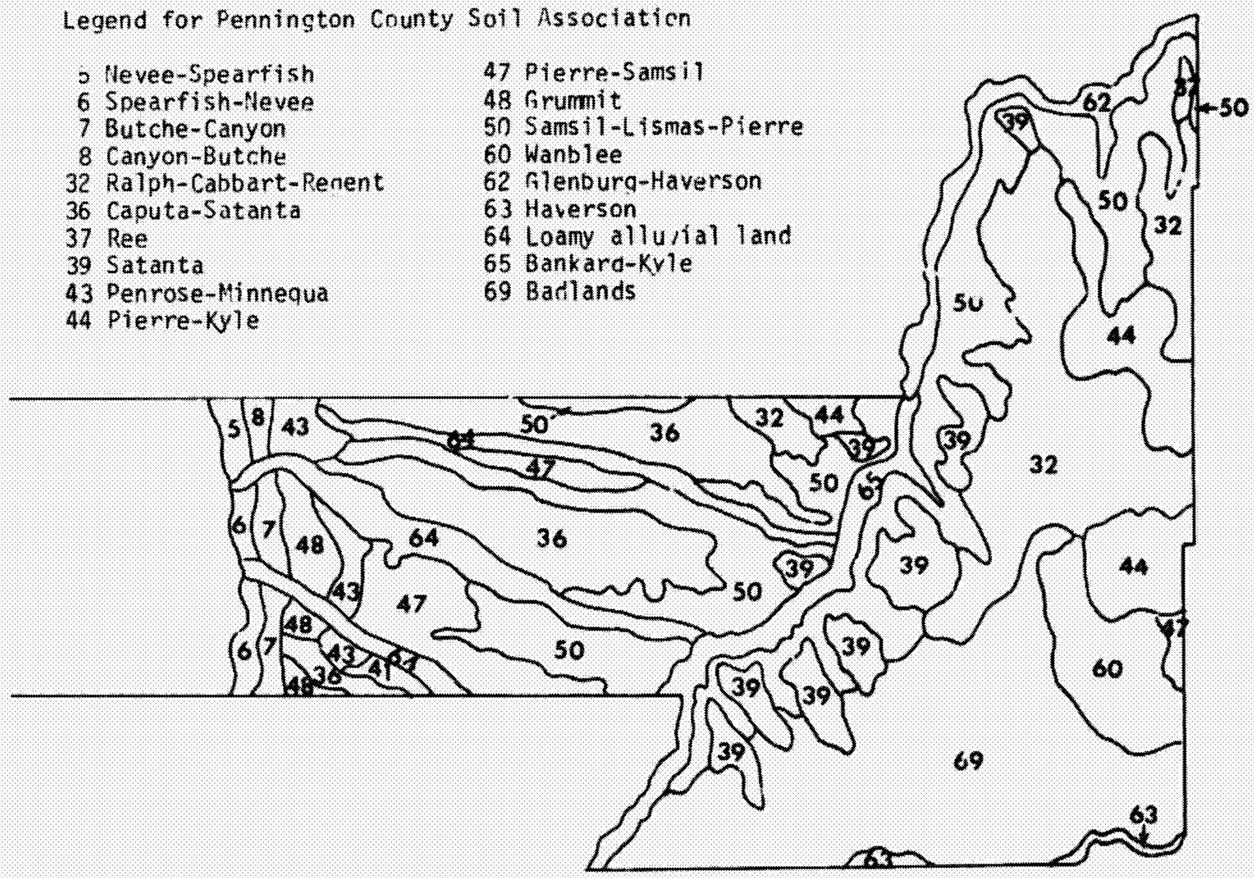


Figure 14. Current soil association map of eastern Pennington County (Westin and Bannister, 1971). Original scale = 1:500,00.

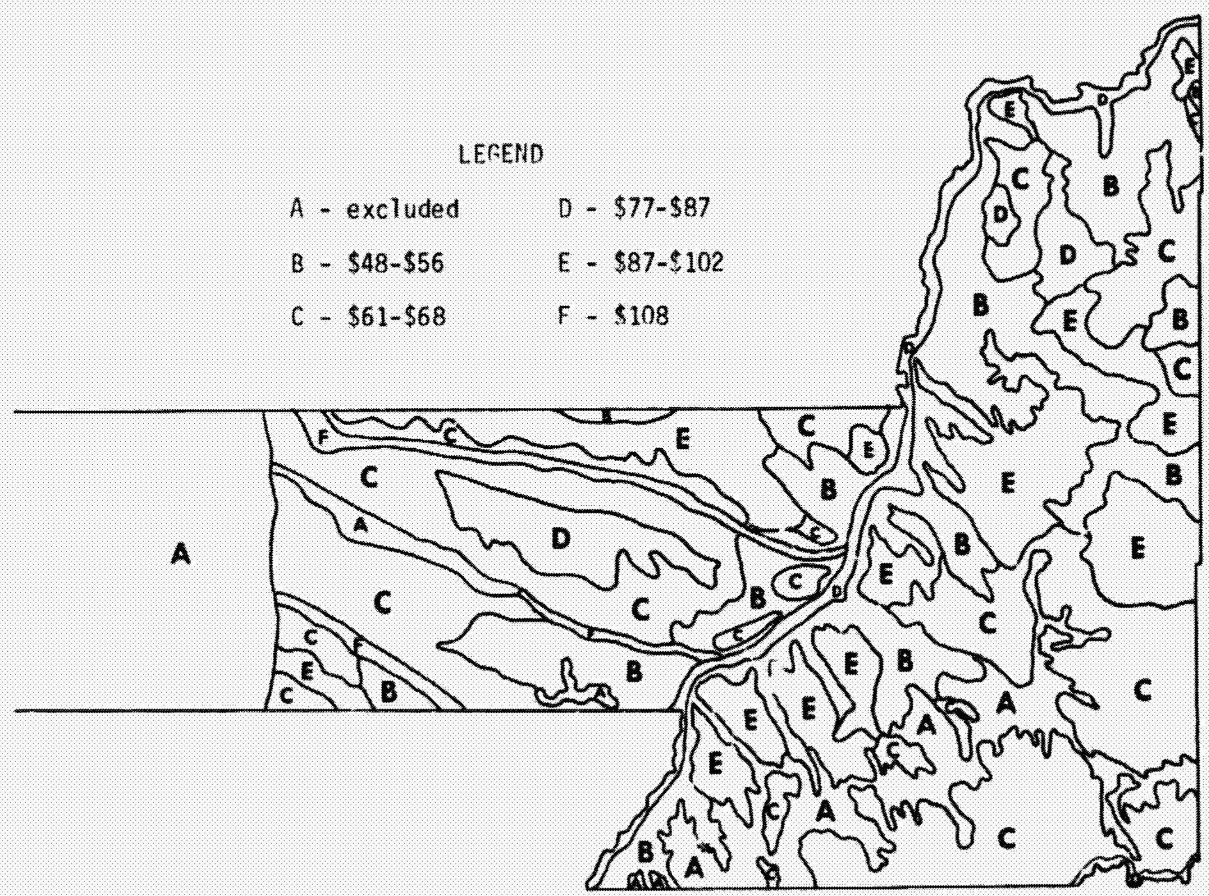


Figure 15. Land value map of eastern Pennington County.

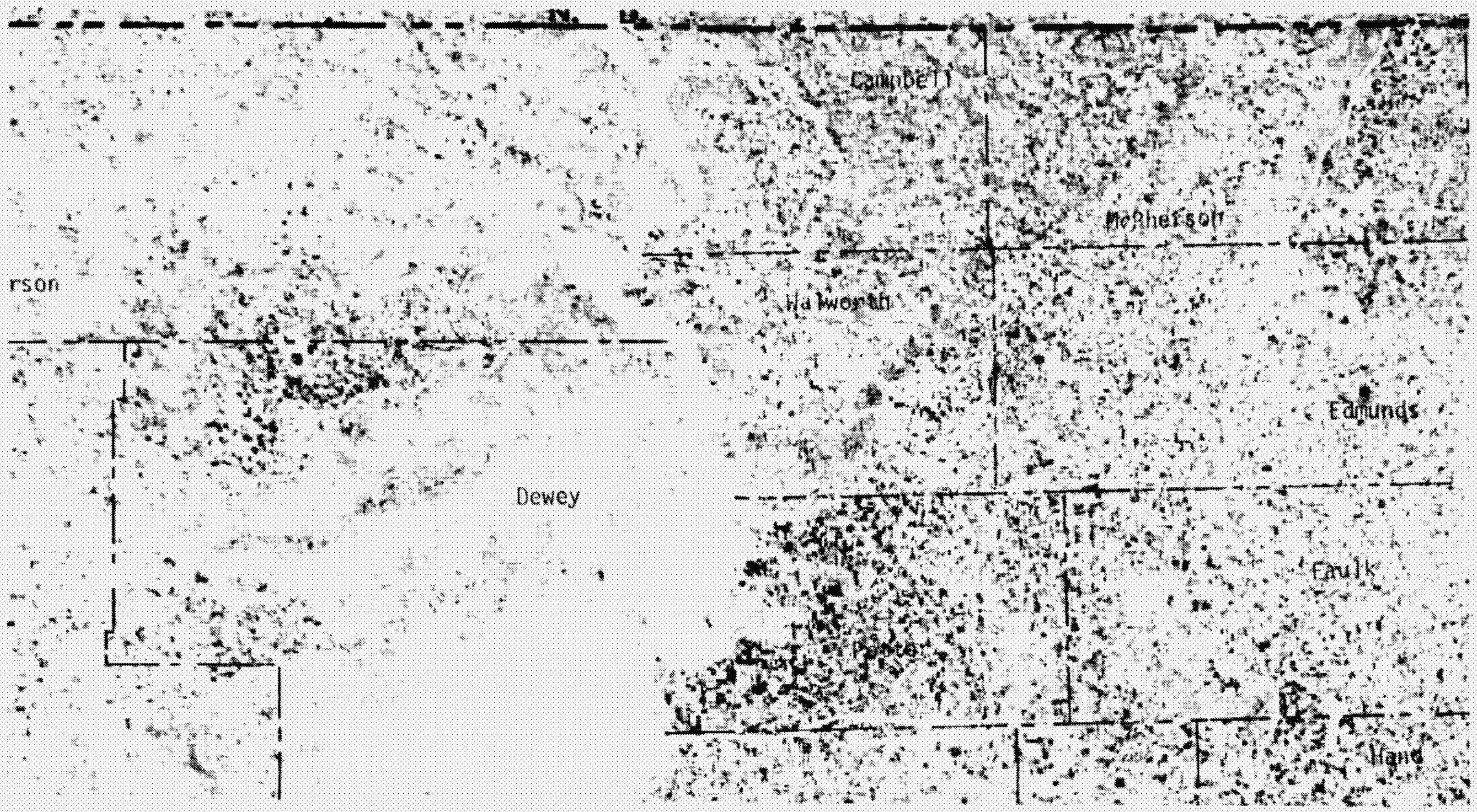


Figure 16. Part of LANDSAT-1 mosaic with soil association boundaries-north central South Dakota. Negative print. Scale about 1:1,000,000.

DELINEATION OF THE BOUNDARIES OF A BURIED PRE-GLACIAL VALLEY WITH LANDSAT-1 DATA A-7

By J. B. Peterson, F. E. Goodrick and W. N. Melhorn
Purdue University, West Lafayette, Indiana

N76-17476

ABSTRACT

The continuity of a narrow meandering strip of Udoll (prairie) soils running east and west for approximately 40 miles across north central Indiana in an area predominantly of Udalfs (timber soils) is apparent in LANDSAT-1 (ERTS-1) data. The dark Udoll soils occur in predominantly flat topography contrasting sharply in satellite imagery from surrounding light colored Udalf soils in the characteristically rolling, undeveloped landscape of the late Wisconsin till plains.

The data for the LANDSAT-1 imagery over central Indiana for June 9, 1973 were processed through a clustering procedure and classified with resulting increased definition of the boundaries among soils grouped according to nine categories and vegetation to two categories of reflectance.

This dark stretch of prairie soil is believed to have formed in the heavy textured, poorly drained glacial debris which filled a major pre-glacial tributary of the Teays River system. This valley was apparently reoccupied and partly reexcavated by surface drainage during interglacial times following retreat of the Kansan and Illinoian age ice invasions. Final filling of the valley occurred during retreat of the East White sublobe of the Wisconsin stage ice.

Interestingly enough, the origin and the continuity of this meandering stretch of prairie was not recognized by soil scientists who over a 60 year period, mapped the three counties which encompass it. Furthermore, geologists who had been searching for the exact location of this buried valley had been unsuccessful until the LANDSAT data provided an adequate synoptic view.

Ready identification and location of the valley has significance to soil survey and land classification people as a guide to soil classification and land use and to geologists as a guide to location of a potentially economically significant aquifer.

INTRODUCTION

LANDSAT-1 data for west central Indiana revealed an anomalous reach of dark land meandering in an east-west direction through an area of lighter colored soils. Field studies of the soils and geology of the region reveal the dark area to consist predominantly of prairie soils in contrast to surrounding timber soils. Also the dark strip is found to delineate a long sought buried tributary of the Teays preglacial river system.

The results of the study suggest a technique for using LANDSAT data to locate other buried valleys which may be important sources of ground water and mineral deposits.

TECHNIQUES

Multispectral scanner data acquired during a LANDSAT-1 overpass on June 9, 1973 was classified with the standard LARSYS classification procedure into eleven spectral classes: five classes of very dark-colored soils, two of soils of intermediate tone, two of light-colored soils, and two of green vegetation. Corn and soybeans, which covered most of the cultivated land in this area in the 1973 growing season, by June 9 had not produced enough canopy to interfere noticeably with the reflected radiance from bare soil. A plot of relative reflectance was made along a north-south transect south of Frankfort, Indiana and perpendicular to the east-west reach of dark-colored soil.

DISCUSSION

The continuity of a long, narrow, meandering strip of prairie soils traversing approximately 65 km in an east-west direction across north-central Indiana was first noted on LANDSAT-1 imag-y. This particular reach of dark-colored soils, although mentioned as a local phenomenon in three individual county soil survey reports, was not previously

recognized as a continuous feature. Early residents also apparently were unaware of the true extent of this long, ribbon-like stretch of dark-colored land, because they gave it local names at different places, such as Round Prairie, Clinton Prairie, Twelve Mile Prairie, and Vinton Prairie.

In Figure 1 the stretch of dark-colored soil is seen meandering through and bounded by the lighter colored soils which are predominant in this region. The plot of reflectance across the dark soil area shows measureably lower reflectance of the dark area (Figure 2).

The dark-colored soils are of the Aquoll and Udoll suborders. These soils have developed under grassland vegetation. The Aquolls represent more poorly drained soils than the Udolls. The lighter colored, surrounding land consists primarily of Udalfs, soils developed under northern hardwood forests. Pioneers found the light-colored soils dominant on the undulating till plain terrain, which was heavily forested with such deciduous trees as walnut, poplar, hickory, beech and oak. Before artificial drainage and cultivation, the linear, meandering stretch of flat, dark-colored land was mostly poorly drained and vegetated with grasses, commonly "marsh grasses".

The darkness of Udoll and Aquoll soils, in contrast to the lighter colored Udalfs, results from a balance between additions of organic matter to their surface layer and the rate of decomposition. The equilibrium level for organic matter content and consequently darkness of color typically is greater in the surface layers of grassland soils than in timbered soils.

Specially trained crews of soil scientists have on two occasions mapped the area in detail without recognizing that the dark-colored soils belong to a single linear, long, meandering strip of terrain (Hurst and Grimes, 1914, Tharp et al, 1914, Ulrich et al, 1959). Had this fact been discerned at the beginning of soil survey work in this area, the survey would have been expedited more quickly and effectively and costs reduced. Geological field studies, using conventional surface mapping and subsurface analysis of water well records, had suggested as early as 1915 that a buried preglacial valley might traverse the area. However, the synoptic view provided by LANDSAT-1 imagery shows the true extent and character of the dark-colored soil, permits a more accurate definition of the probable course and boundaries of the ancient stream, and reveals regional relationships which previously could only be surmised from extant data.

The area is located just a few miles east of the classic eastern boundary of the Prairie Peninsula or Prairie Point which extends from the west into lands predominantly covered by hardwood forests at the time of settlement. (Trewartha, 1968, Brochert, 1950). The anomalous extension of grasslands into an area where the macroclimate favors hardwood forests results from the flat topography and fine-textured surface material filling the old valley. These naturally poorly drained soils favor grasses rather than trees.

This buried valley, recently named the Clarks Hill Valley (Maarouf and Melhorn, 1974) on the basis of subsurface geological analysis, is evidently a major preglacial tributary of the Teays River system. This valley was apparently reoccupied and at least partly reexcavated by surface drainage during interglacial times following retreat of the Kansan and Illinoian age ice invasions. Final filling of the valley occurred during retreat of the East White sublobe of the Wisconsinan stage ice. This recession also produced a rather flat till plain surmounted by a few crevasse-fill deposits or kames. The old valley may have remained slightly lower topographically even during retreat of the Wisconsinan ice, and for a time may have provided ice border drainage to the newly-formed Wabash River below Lafayette. With gradual cessation of meltwater flow, the linear depression became a series of ponds or sloughs which infilled with lacustrine silts and clays or colluvial deposits. This eventually raised the old valley floor level nearly to that of the adjacent terrain. The Udoll and Aquoll soils seen on the LANDSAT-1 imagery developed on these infill materials.

These differences in soils and terrain of the valley compared with the surrounding lands has a noticeable effect today on farming practices and economic conditions. Figure 3 shows a farmstead in the valley fill area with typically new and abundant grain storage equipment, whereas Figure 4 shows a typically modest farmstead in the rolling terrain and lighter colored soils of the till plain which surrounds the valley.

CONCLUSIONS

The results of this study suggest that elsewhere in the glaciated plains region of central North America, machine classification of spectral response from soils and vegetation may have value in defining and tracing similar buried valleys whose position is poorly known or whose presence is only suspected. The valleys are locally important sources of groundwater and industrial mineral deposits.

LITERATURE CITED

BROCHERT, J., 1950, "The Climate of the Central North America Grass Land". Ann. Assoc. American Geographers, 40; 1-39.

HURST, L. A. and GRIMES, E. J., 1914, "Soil Survey of Tipton County, Indiana, USDA," (Advanced Sheets - Field Operations of the Bureau of Soils, 1912.)

MAAROUF, A.M.S. and MELHORN, W. N., 1974, "Hydrology of Glacial Deposition in Tippecanoe County, Indiana". Indiana Department of Natural Resources Geological Survey Paper. (In Process).

THARP, W.E., PEACOCK, R. H. and ROSE, C.M., 1914, "Soil Survey of Clinton County, Indiana, USDA", (Advanced Sheets - Field Operations of the Bureau of Soils, 1912). Government Printing Office, Washington, D.C.

TREWARTHA, G.T. 1968, "Classification of Climates and The World Pattern". pp 237-253. In an Introduction to Climate". McGraw-Hill Book Co., New York.

ULRICH, H.P. et al, 1959, Soil Survey of Tippecanoe County Indiana. USDA, SCS, Series 1940, no. 22., Government Printing Office, Washington, D.C.

ACKNOWLEDGEMENT

This research was conducted under NASA Contract NAS 9-14016 and NASA Grant NGL 15-005-186.

Figure 1. Dark-colored Udoll and Aquoll soils delineate the surface of a buried preglacial valley in Indiana.

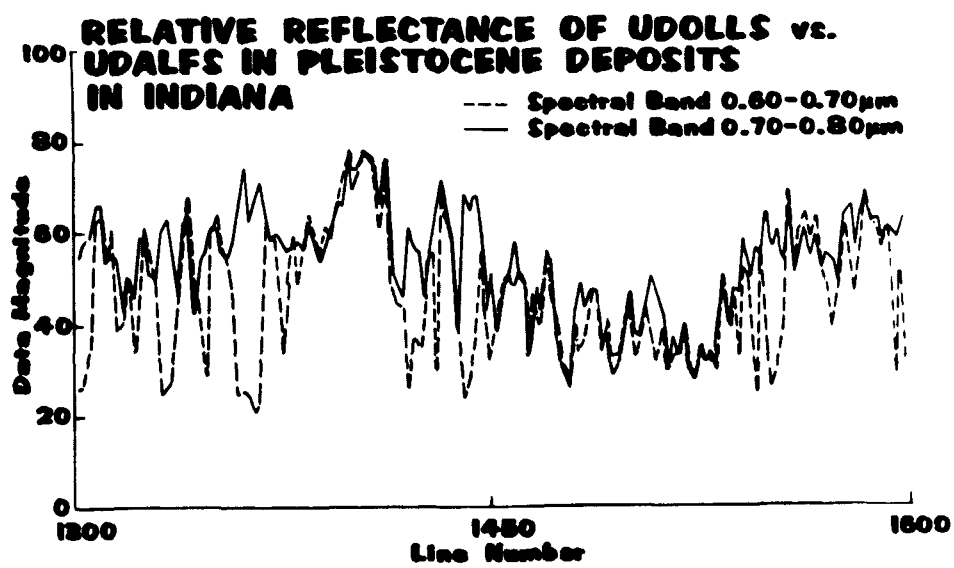


Figure 2. Relative Reflectance along north-south transect across buried Clarks Hill Valley. Reflectance is lower across the darker soil.

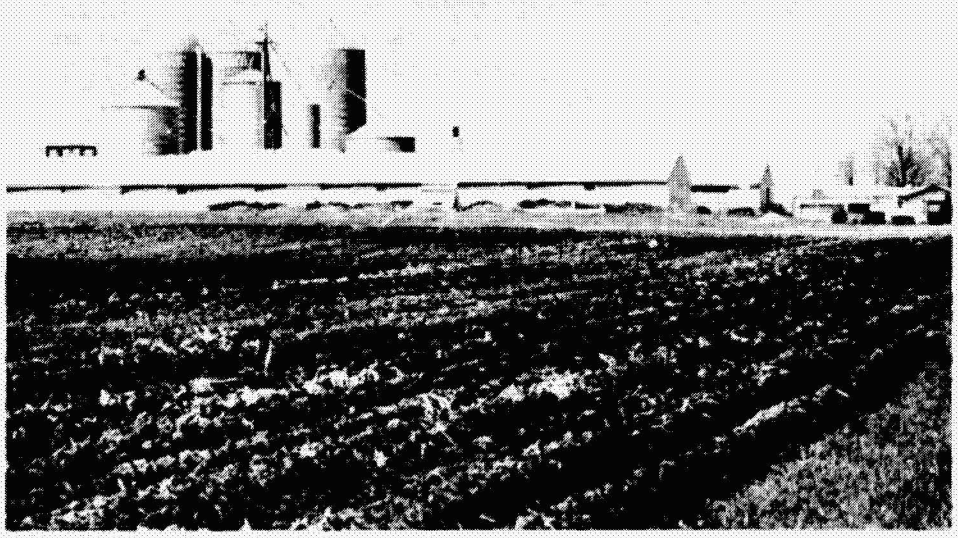


Figure 3. Homestead on Aquoll soils on surface of buried Clarks Hill Valley reflects high soil productivity.

Figure 4. Homestead on Udalf Soils reflects lower productivity than found on Udoll and Aquoll soils of the adjacent Clarks Hill Valley.

ARE CLEAR-CUT AREAS ESTIMATED FROM LANDSAT IMAGERY RELIABLE?

A-8

By Y. Jim Lee, Pacific Forest Research Centre, Canadian Forestry Service, Environment Canada, 506 West Burnside Road, Victoria, B.C., Canada, V8Z 1M5.

N76-17477

ABSTRACT

The reliability of LANDSAT imagery for estimation of clear-cut areas was evaluated by comparison with data obtained from high-altitude photos and logging historical map and from field inspections.

A mature forest, owned by Pacific Logging Company, was selected as a test site because of its continuous clear-cut operation. The forest is about 50 km northwest of Victoria, British Columbia, Canada, and consists of 9092 ha. Ground truth was based on high-altitude photos and the Pacific Logging Company Logging History Map for 1973, with a scale of 1:63,360. LANDSAT imagery from band 5, recorded by multispectral scanner, was obtained on September 4, 1972 and on August 12, 1973.

Areas clear-cut within the past year were overestimated by 12.9% (105 ha), those clear-cut 1-year or more by 2.2% (76ha), whereas uncut mature timber was underestimated by 3.6%(176 ha). Three clear-cut areas were missed in the company map and two in the LANDSAT enhancement. The difference between area estimates was significant when all 26 areas were included but not when 2 overestimated areas were excluded from the analysis.

Some of the difficulties in using the technique are discussed, but the study indicates that LANDSAT imagery color enhancement is a useful tool in up-dating clear-cut areas for long-term planning in forest management.

INTRODUCTION

Logging has been a continuous operation in the Province of British Columbia since the earliest days of settlement. Accounting for the acreage logged annually is desirable for long-term planning, but it is also a tremendous task, expensive and time-consuming to carry out by conventional means. LANDSAT offers a new and unique periodic overview of forest lands and could facilitate economic collection of such useful data. Earlier studies indicated that some forest management operations can be monitored (Lee, 1974) and the technique of color additive viewer enhancement facilitated the interpretation of a dynamic event over time, such as clear-cut areas (Lee *et al.*, 1974). By adjusting the light intensity illuminating each band and the scale of each image on the color additive viewer, multi-date imagery can be superimposed to enhance the scene. This technique is especially useful for areas that have been clear-cut within the past year, where the LANDSAT signature responds to reflectance from exposed mineral soil. The purpose of this paper is to demonstrate that clear-cut areas and uncut mature timber can be identified and the acreage estimated, using LANDSAT imagery.

METHODS

The mature forest, owned by Pacific Logging Company, Victoria, British Columbia, was selected as a test site because of its continuous clear-cut operation. The forest is a typical old-growth type in the Pacific Northwest region, consisting of mainly Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), with western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and other coastal tree species as minor components. It is located about 50 km

 PRECEDING PAGE BLANK NOT F

northwest of Victoria, British Columbia, Canada, and consists of 9092 ha.

Ground truth was based on high-altitude color photography (scale 1:120,000) and the Pacific Logging Company Logging History Map for 1973, with a scale of 1:63,360, and field visits. The high-altitude color photographs were taken on August 6, 1972 and on July 19, 1973, from Falcon and CF-100 jet aircrafts, each equipped with RC10 and four Vinten 70-mm cameras. LANDSAT imagery from the 4 bands recorded by the multispectral scanner (MSS) was obtained on September 4, 1972 and on August 12, 1973.

Five steps were required in order to produce satisfactory data from multi-date LANDSAT imagery. The first step was to cut out the portion containing the test site from the 23 cm x 23 cm black and white MSS 5 imagery for both September 4, 1972 and August 12, 1973, and to mount them between "anti-Newton ring" lantern slide glass. The second step was to place the slides in a color additive viewer. The third step was to adjust the scale so that the multi-date images were superimposed. The fourth step was to give the right amount of light intensity, and to use a red filter for the September 4, 1972 imagery and a green filter for the August 12, 1973 imagery. The final step was to photograph the scene on the screen of the color additive viewer, using 35 mm color slide film.

A 35 mm slide projector was used to transfer the clear-cut information onto a map, comparable to the Pacific Logging Company Logging History Map for acreage estimation.

A systematic Dot-Area-Grid, 15.5 dots per cm^2, was used to estimate acreage of the forest types, totalling 26 areas (Figures 1 and 2).

RESULTS AND DISCUSSIONS

Image interpretation

Image analysis of high-altitude photos (Figures 3 and 4) and confirmation from field visits indicate that progress of clear-cutting can be identified from LANDSAT imagery (Figures 5 and 6) and multi-date enhanced color prints (Figure 7). Three distinct forest types can be identified: (1) areas clear-cut within the past year, (2) areas clear-cut 1 year or more, and (3) areas of uncut mature timber. Areas clear-cut within the past year showed up much lighter in color or in tone (owing to fresh slash and exposure of mineral soil) than those areas clear-cut 1 year or more, with or without slash burn (owing to gray slash, planted tre[illegible] plus grass and shrubs and burned slash), as seen in Figures 3, 4, 5 and 6 (see arrows[illegible] he differences in color among the 3 forest types as seen in the multi-date enhanced col[illegible] rint (Figure 7) are the most distinctive where areas clear-cut within the past year are red, areas clear-cut 1 year or more are yellow, and areas of uncut mature timber are dark gray. In areas where mineral soil or rocks are exposed for several years, the distinction between 1-year-old and older clear-cut areas may not be possible.

Transferring of Forest Types Onto Map

Obviously, the question will be asked, "How can the forest types best be transferred onto a map?" Initially, an attempt was made to use the August 12, 1973 black and white LANDSAT MSS 5 imagery and a 35 mm slide projector to transfer the forest types onto the map. This procedure was not successful because of the fuzzy forest type boundaries. However, when the multi-date enhanced 35 mm color slide (Figure 7) was used, the transformation was more successful because the type boundaries were quite clear. Some difficulty was encountered in the transferring process, possibly due to the distortion of the multi-date enhanced slide and the positioning of the 35 mm slide projector; so projection was done in small areas, 2 to 4 cm at a time. From experience, the author believes that if an Interpretoskop is available, this difficulty might be eliminated. Transformation of forest types can

probably be done directly, using LANDSAT color composite MSS bands 4, 5 and 7 or diazo color composites (Lee et al., 1974).

The map (Figure 1), produced by the process, is similar to the one provided by the Pacific Logging Company showing areas clear-cut in 1973 and before 1973.

Area Estimates

Ideally, area calculations should be done by overlaying the maps in a grid format on a digitizing machine. This machine was not available, hence area estimation was resolved by dot grids. Therefore, the error in area estimates from dot grids, if any, is vested in the process (Bonner, 1975). This error is not serious in the overall estimates between the 2 maps: 5 ha or 0.1%; but it may have some effect on each individual area estimate of the 26 areas. Table 1 is a summary of the two area estimates for each of the 26 areas and their differences.

In spite of this shortcoming, the resulting area estimates were satisfactory:

(1) Areas clear-cut within the past year were overestimated by 105 ha or 12.9% only.
(2) Areas clear-cut 1 year or more were overestimated by 76 ha or 2.2% only.
(3) Areas of uncut mature timber were underestimated by 176 ha or 3.6% only.

A number of discrepancies, most of which were small, were found in the areas clear-cut within the past year. Area numbers 1, 2 and 11 were incorrectly classified by the company in its mapping process, while area numbers 7 and 14 were incorrectly classified in the LANDSAT mapping process. Area numbers 4 and 14 were significantly overestimated in the LANDSAT mapping process, 50.8% and 82.4%, respectively.

Significant differences were found to exist between area estimates from the company map and from the LANDSAT enhancement when all 26 areas were included (Chi-square: 80.80 with 25 degrees of freedom). However, the differences were not significant when area numbers 4 and 14 were excluded from the analysis (Chi-square: 40.99 with 23 degrees of freedom). In the LANDSAT mapping process, the total clear-cut area was overestimated by only 181 ha or 4.2%.

Attention should be drawn to the fact that the period for LANDSAT clear-cut area estimates was between September 4, 1972 and August 12, 1973, but the period for company clear-cut area estimates was the 1973 calendar year. Therefore, a slight discrepancy in area estimates was expected.

CONCLUSIONS

The ability to identify the status and to estimate the size of current and past clear-cutting activity has been definitely established. The acreages for clear-cut and uncut mature timber determined from LANDSAT imagery are reliable and the LANDSAT color enhancement technique is a useful tool in up-dating clear-cut areas for long-term planning in forest management.

ACKNOWLEDGMENT

Thanks are due to Canada Centre for Remote Sensing, Ottawa for making available a Color Additive Viewer. The cooperation of Mr. W. J. Bruce Devitt of the Pacific Logging Company, Victoria, British Columbia, Canada in making available information for the test site is gratefully acknowledged.

REFERENCES

Bonner, G.M. 1975. The Error of Area Estimates From Dot Grids. Canadian Journal of Forest Research 5(1): 10-17.

Lee, Y.J. 1974. Monitoring Forest Management Operations. Canadian Surveyor, 28(2): 135-141.

Lee, Y.J., E.T. Oswald and J.W.E. Harris. 1974. A Preliminary Evaluation of ERTS Imagery For Forest Land Management in British Columbia. Second Canadian Symposium on Remote Sensing, Univ. of Guelph, Guelph, Ontario April 29, 30 and May 1, pp. 87-101.

TABLE I SUMMARY OF AREA ESTIMATES

Forest Type	Type No	Pacific Logging Co. Logging History, ha (A)	LANDSAT Color Additive Viewer Enhancement Logging History ha (B)	Difference ha (C)	(C)/(A) X 100%
Logged in 1973	1	60	60	0	0
	2	57	75	-18	-31.6
	3	39	44	- 5	-12.8
	4	65	98	-33	-50.8
	5	52	54	- 2	- 3.8
	6	134	132	2	1.5
	7	11	13	- 2	-18.2
	8	13	11	2	15.4
	9	44	44	0	0
	10	77	75	2	2.6
	11	106	101	5	4.7
	12	44	49	-5	-11.4
	13	75	98	-23	-30.7
	14	34	62	-28	-82.4
	Subtotal	811	916	-105	-12.9
Logged before 1973	15	98	98	0	0
	16	477	502	-25	-5.2
	17	300	321	-21	-7.0
	18	495	538	-43	-8.7
	19	1580	1531	49	3.1
	20	534	570	-36	-6.7
	Subtotal	3484	3560	-76	- 2.2
Uncut Mature Timber	21	3496	3401	95	2.7
	22	28	36	- 8	-28.6
	23	75	73	2	2.7
	24	476	476	0	0
	25	660	583	77	11.7
	26	62	52	10	16.1
	Subtotal	4797	4621	176	3.7
Total		9092	9097	-5	-0.1

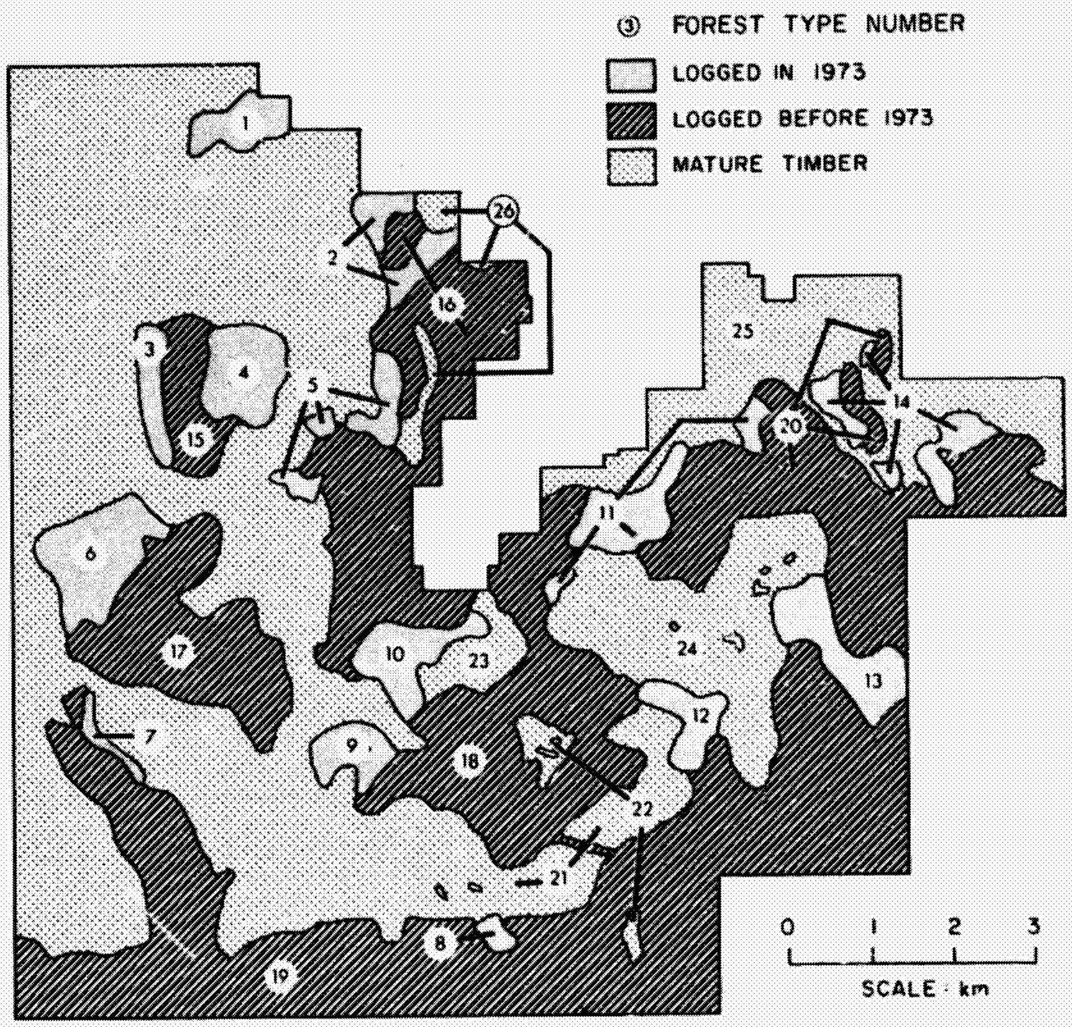


Figure 1. Logging history map produced from LANDSAT imagery Color Additive Viewer enhancement. (Forest type numbers also correspond to type numbers in Table I).

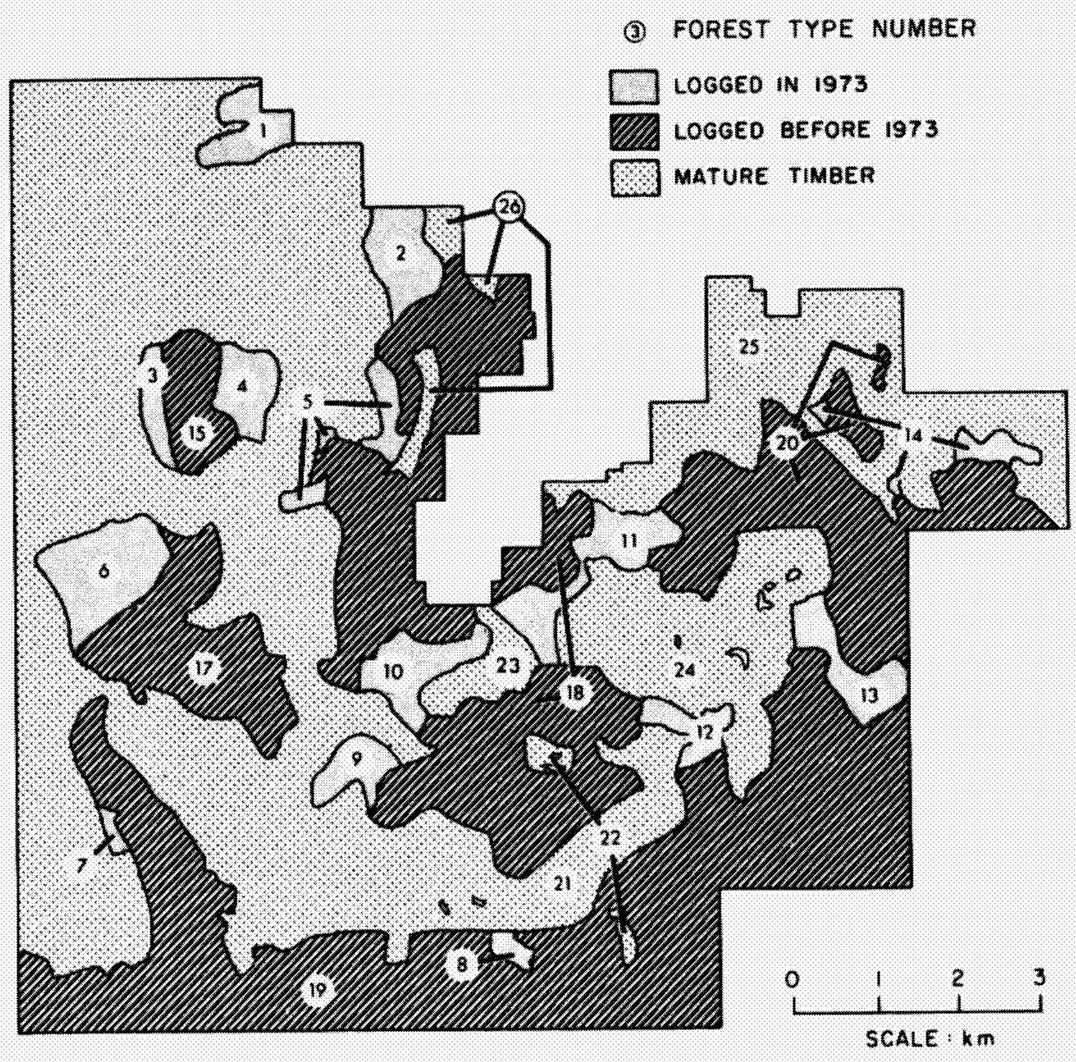


Figure 2. Pacific Logging Company logging history map. (Forest type numbers also correspond to type numbers in Table I).

Figure 3. Part of a 23 cm x 23 cm high-altitude color photo taken on August 6, 1972, showing the test site. Arrows point to timber to be logged in 1973.

Figure 4. Part of a 23 cm x 23 cm high-altitude color photo taken on July 19, 1973, showing the test site. Arrows point to area logged in 1973.

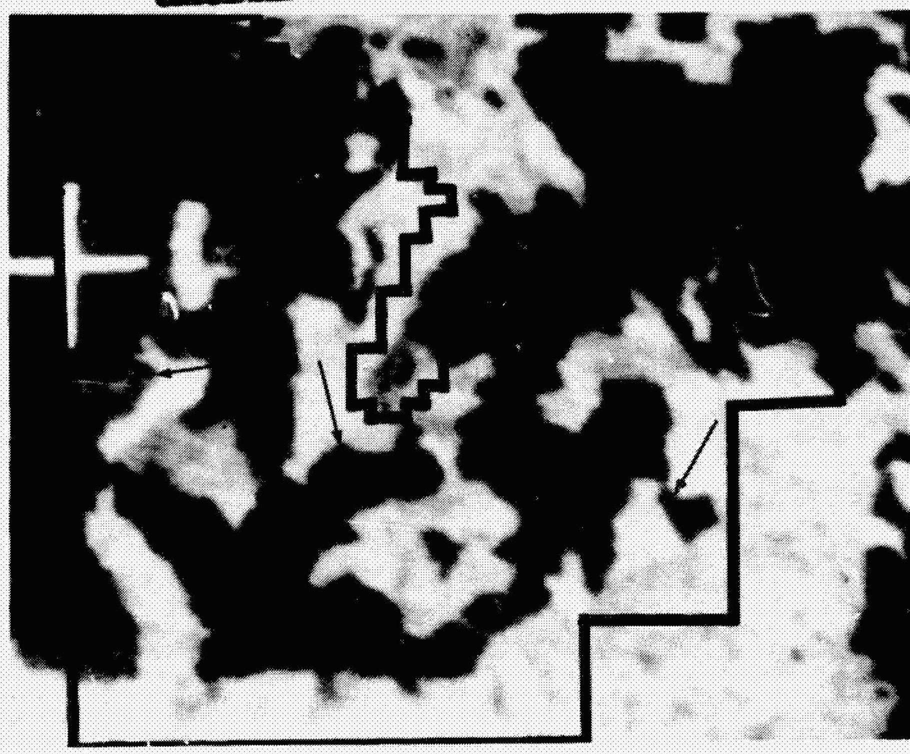


Figure 5. An enlargement of LANDSAT-1 imagery from frame 1043-18370 MSS-5 (September 4, 1972), showing the test site. Arrows point to timber to be logged in 1973.

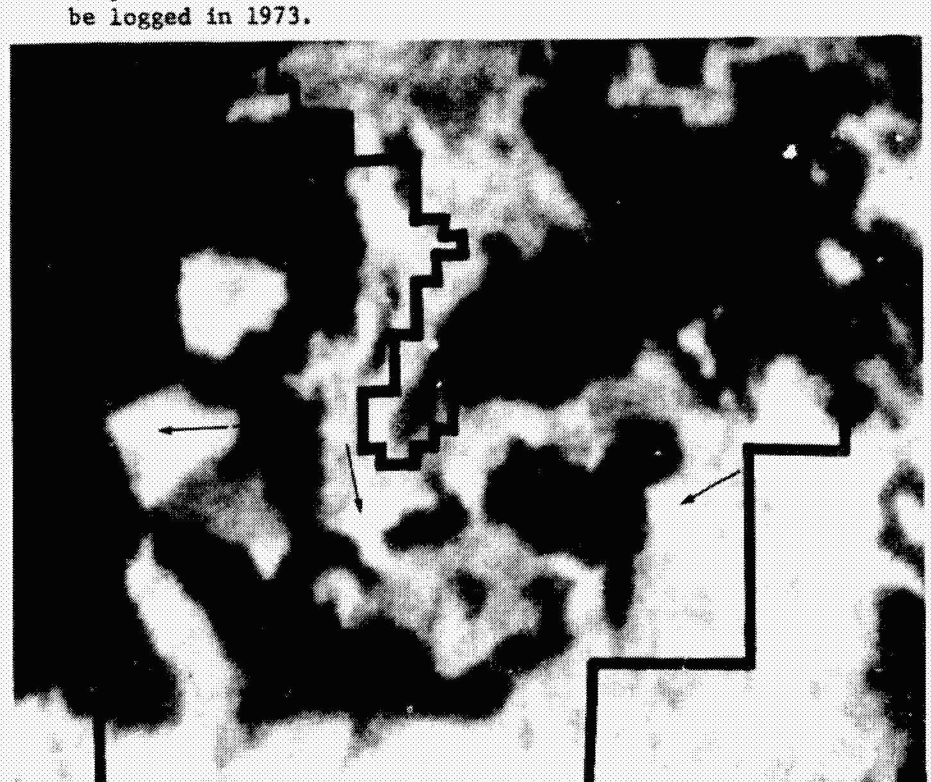


Figure 6. An enlargement of LANDSAT-1 imagery from frame 1385-18365 MSS-5 (August 12, 1973), showing the test site. Arrows point to area logged in 1973.

Figure 7. Color Additive Viewer enhancement of logged areas (in red color, see arrows), using LANDSAT frame 1043-18370 MSS-5 (September 4, 1972) with red filter superimposed on frame 1385-18365 MSS-5 (August 12, 1973) with green filter.

A-10

OPERATIONAL CONSIDERATIONS FOR THE APPLICATION OF REMOTELY SENSED FOREST DATA FROM LANDSAT OR OTHER AIRBORNE PLATFORMS

By G. Robinson Barker and Terrance P. Fethe
St. Regis Paper Company, Southern Timberlands Division, Jacksonville, Florida

N76-17478

ABSTRACT

The forest data base requirements necessary to efficiently manage a large timber based forest industry of the 1970's have transcended by a considerable margin those data required two decades ago. These data demands have grown both in quantitative terms and in the level of precision acceptable to successfully undertake the multiple decision making processes required.

From the traditional generation of area/volume and frequency tables used in immediate planning for harvest and cultural activity, data are now subjected to the rigors of long range planning manipulations, as these data represent the major input to such planning models. To be effective in such planning activity, the data must be provided in a timely manner. Concurrent with the increase in data demand and the speed of preparation, has been the ever increasing difficulty in securing and reducing these data within the timetables demanded.

Remote sensing techniques at all levels seemed to offer the most promising prospect in satisfying the data requirements, and in alleviating the difficult task of collecting the data. After a thorough review of the technology of remote sensing and the state of the art of interpretation, it was realized that the best hope for a practical, implementable scheme was to approach the problem in three phases, all interrelated, but independent enough to allow for the progressive modular development of a multi-level sampling system. At each stage, operational feasibility will be evaluated so necessary revisions can be integrated into the system as needed.

INTRODUCTION

St. Regis Paper Company, Southern Timberlands Division, has been involved since 1971 in investigating the possibility of utilizing remotely sensed data as a viable data source in establishing a practical forest information system. The collection of the data must be economically feasible and the results applicable to large non-contiguous forest land holdings in the Southeastern Coastal Plain provinces of the United States, with precision levels commensurate with a broad range of user requirements.

Statement of the Problem and Background

Nature of the Problem.- With the inception of active forest management practices in the United States at the turn of the century, and especially with the intensification of these practices in the post World War II years, specifically in the South, a significant part of forest management activity has been devoted to the definition of the forest complex in terms of:

. quantitative standing timber values
. patterns of stand structure and conditions
. dynamic response of the forest over time.

Quantitative Timber Values: Quantitative timber values refers here to those measurable quantities of interest defining timber as a raw material in terms of commercial units of value (cubic feet, cubic meters, board feet, tons, frequency, etc.). These values are important not only in describing the gross raw material availability as a single value, but also in providing a quantitative measure for alternative uses available from the timber supply on hand.

Forest Stand Structure and Condition: Very seldom is a forest described as a whole, but rather a conglomerate of many forest cover type components, occurring as a result of natural forest progression or from conditions resulting from man's cultural activity. While quantitative timber values describe the sum of individual tree measurements, stand structure and conditions describes the timber stands as productive entities. Structurally, stands are evaluated as to species composition, age classes of significance and density of stocking. Stand condition reflects the environmental situation under which the timber is growing, and the productivity (growth) potential as indicated by topographic position and growing site. Growing site is here defined as an index value relative to productive potential.

Stands then, are vegetative associations with individual quantitative values and growth characteristics. Stands may also constitute non-vegetative entities undergoing cultural transition, but are still considered part of the overall forest.

Dynamic Response of the Forest Over Time: Dynamic response refers to the growth and net change occurring throughout the forest complex over periods of time. Such growth represents the aggregate growth and net change over the whole forest represented by its constituent stands.

Magnitude of the Problem.-Any large wood-using manufacturing facility such as a pulp and paper company requires many hectares (acres) of timberland to support the raw material demand of the mills[1/]. St. Regis, as a typical, large forest products company, owns or controls over 2.3 million hectares (5.7 million acres) in Continental United States and Canada. From these lands raw material is supplied to seven pulp mills and at least five saw mills producing products from wood studs to finish veneers. The extent of St. Regis land holdings is summarized in Table I.

As an operating division of the Corporation, Southern Timberlands includes over 680 thousand hectares (1.7 million acres) of forest land owned or controlled. From these lands, three pulp manufacturing facilities draw approximately 30 percent of their raw materials. When the lands are under full production, it is anticipated that company produced raw material will approach 70 percent of the mill requirements.

Geographically the three mill regions within Southern Timberlands are illustrated in figure 1. The mill regions comprise the major administrative subdivisions within the Division and are identified as the Jacksonville, Pensacola and Mississippi

---

1/ Throughout this study, common units of measure were used in lieu of SI units; thus, area = acres, volume = cubic feet, length = feet, or chains (66 feet).

Regions. The administrative components of these subdivisions are illustrated in figure 2. Relative area values are included for comparison.

Districts are the largest administrative subdivision within a mill region, and are usually composed of fee lands, and several ownerships. These ownerships represent the more than 90 leases and timber purchase contracts making up the 380 thousand hectares (949 thousand acres) of controlled land in the South; Table II.

Ownerships and fee blocks are further subdivided into Administrative Units. As the name implies, these are units maintained for record keeping and locational convenience. The smallest and most vital land subdivision within the Southern Timberlands is the Operating Area. Far more than mere administrative subdivisions, Operating Areas are functional biological data units from which information at all levels is derived. The evolutionary history of the Operating Area is an interesting one and reflects at once the traditional approach to the data acquisition problem and the vector with which remote sensing technology might be integrated with established procedure, to provide a timely data base of quantity, and precision to meet the current and future needs of management.

Background.- From the beginning of forest management in the South, the problem of securing adequate data from the forest has existed, and various schemes for gathering this information have formed an integral part of most forest management activity. Whether such data were manifested as cryptic scribblings on the back of an envelope or a totally automated information system, the basic objective has been the same; to establish current quantitative timber values associated with a heterogeneous array of timbered and non-timbered stands, and to identify and measure those variables most significant in the prediction of future quantitative timber values and stand profiles.

In the early 1950's an elaborate management plan was developed for Southern Timberlands utilizing the best information available. The core of this plan was an extensive inventory carried out by a light ground sample and photo interpretation of modified infra-red black and white images flown in 1952. The objective of this plan was to achieve even-aged management within one or two rotations through a checkerboard cutting pattern.

During this same period of time, a new ground sampling concept was introduced to southern forest managers. Called Continuous Forest Inventory by its developers, this technique was later revised and renamed Permanent Growth Sample (PGS). This sampling scheme was based upon permanent plot locations established on a very wide grid. Periodically measured on a three to five year basis, PGS was designed to provide overall forest statistics, and to establish growth and net change patterns. With very precise measurements as a feature, the prime objective of PGS was to establish growth rates either empirically or through regression techniques for the forest as stratified by those parameters most contributory in growth prediction, i.e., site, age and density.

Results from PGS highlighted two important points:

1. The variables controlling the growth patterns of the forest were not adaptable to rectangular management units, but rather, were closely allied with the criteria as earlier defined for a stand.

2. PGS could not stand alone efficiently as a data source in providing

information on volume and stand composition, in addition to growth and net change.

From the above, it was determined a different forest sampling technique was necessary to properly define volume and stand composition, and that any such scheme must use the stand as a primary unit of inventory since this vegetative association would be projected through time.

Parallel development of computer technology, both in hardware and software, cast forest data acquisition in a new light. The tools of operations research; linear programming, forest simulation, and mathematical scheduling provided the means for the development of long range planning models. The scope of data required increased, the quality of the data became more stringent and the timeliness of the generated information became vital. Inventory results became the main input source to these upper echelon planning models. Since small errors magnify, given the ingredient of time, the precision of this input became critical.

Since projections are made on an annual basis, the projective unit must be operable; that is, harvested or regenerated, within a year's time. Some stands were just too large to meet this annual operability criterion, and had to be subdivided. The stand and/or its subdivision was redefined as an Operating Area, and became the primary inventory and projective unit. The inventory of these areas became Operating Area Inventory (OAI). Figure 3 is an illustration of the range of data collected on PGS and OAI. Operating Areas became not only the basic inventory and projective units, but also the primary units for management, replacing the rectangular man-made configuration with a biological association whose management was to be optimized with applicable economic standards. Administrative Unit maps are generated from current color photographs flown at a scale of 1:15,840. Figure 4 shows such a photo with delineated Operating Areas and the inventory sample points located as permanent records.

To augment OAI and to insure current data, the basic inventory information is annually updated to the first of the year. The updating file has become the major source of forest information used as input into the long range planning models, and other analyses as may be required within the Division.

Purpose

The data required to measure and establish those parameters of quantitative value, stand structure and composition, growth and net change are broad indeed. Traditional data acquisition procedures are inadequate to acquire the data at a level of precision and speed to meet the current and projected needs of management. Developing methods and techniques to augment the data acquisition activity without sacrificing the accuracy or precision of data collected constitutes the primary thrust of this research activity. As of this writing, no conclusive results have been reached. It is the objective of this report to outline the methods, and where established, the procedures taken in the approach to resolving this problem.

METHODS AND PROCEDURES

Approach

Feasibility Study.- In the early 1970's, remote sensing, as a concept beyond

that of conventional photography, materialized before the general public almost overnight. Replete with unfamiliar data renditions, hardware configurations, computational analysis procedures, and, of course, the associated vernacular, remote sensing developed an aura of mysticism, with a "Buck Rogers" overtone. To a potential user, the urge was to "ride off in all directions at once". St. Regis was no exception. The literature abounded with problems and their solution and it was easy to become enthusiastic over all this new technology and its potential. It soon became apparent that the solutions afforded were for problems we didn't have. For the most part, the resolution of these problems was of academic or local interest only. The question had to be: "Can this new technology, stripped of its shroud of mystery, contribute significantly to the solution of the data acquisition problem within Southern Timberlands?"

It was determined to approach this technology slowly and deliberately through a feasibility study. The objective was, through review of literature, conversing with those working in the area and the attendance of selected short courses, to determine what the real possibilities were, and what techniques held the most promise of success in solving the problem.

After a year and a half, certain conclusions were reached.

1. Operational remotely sensed data acquisition was not yet a reality for the private sector.

2. Digitizing of photographs, either single or multi-band involved so many uncontrolled variables as to render the data analysis questionable at best.

3. Given the data and the proper digitized format, the hardware/software analysis interface was a formidable one requiring high costs for questionable gain. While the hardware (computer capacity) was and had been available, existing software packages were rare, complicated and not tailored for general user applications.

4. The real potential of remote sensing, beyond photogrammetry, was as a tool to augment already ongoing systems, and at least for the present, should not be considered as a stand-alone technique for forest data acquisition.

5. The need for specific problem definition became apparent. Such a definition would include an identification of what was needed, a complete review of known techniques and methodology, and an assessment of what additional capability was necessary to fulfill the Divisional data requirements.

Scope.- The scope of the remote sensing research project, as proposed, is broad, exceeding by far the range of any one study plan. It was proposed to divide the research into three phases; to establish a photo/ground sample correlation, to investigate techniques of multi-spectral digital analysis, and to develop a semi-automated multi-level sampling system. Each phase is to be controlled by a work plan but will be related to the other phases, and in many cases, work will be carried out simultaneously. To properly verify results, research activity will be replicated at least three times throughout the Division. These areas are illustrated in figure 1 and are; Jacksonville Mill Region (J-T), Lower Coastal Plain, Flatwoods, 30,000 hectares (76,000 acres); Pensacola Mill Region (P-T), Middle Coastal Plain, 6,800 hectares

(17,000 acres); and the Mississippi Mill Region (M-T), Middle Coastal Plain, 31,600 hectares (79,000 acres), respectively.

On all three test areas, aerial data were collected at various altitudes, yielding scales of 1:31,680, 1:15,840, and 1:7,920. The data included mylar transparencies and contact prints from color negatives and color infra-red aerial film positive transparencies. It was planned during the process of this investigation to determine an optimum combination of scale and media for interpretation.

I. Photo-Interpretive/Ground Sample Correlation

Hypothesis.- Basic correlation is possible between photo based estimates of forest data and the same data as measured on the ground, such that sample efficiency will be improved enough to significantly reduce the ground sample necessary at the Operating Area level.

Objectives.- The basic objective of this phase of the investigation is to review and gain an expertise in existing photo-interpretive techniques and methodology and to establish a reasonable correlation between ground samples and photo-estimates from low to medium scale photography. To achieve this objective, the photo-interpretive ground sample phase was divided into three investigative segments.

1. A review of statistical design and ground sampling selection criteria and compatibility with photo interpretive techniques.

2. Direct stereo measurement capability in premerchantable, non-commercial, understocked and non-stocked forest land in terms of frequency and area allocations.

3. Direct stereo measurement and estimation capability in merchantable timbered land in terms of relative timber quantities and timber stand conditions, and the establishment of a degree of correlation between such photo estimates, and the corresponding ground sample.

Procedures.- The procedural approach to this phase of the investigation will follow methods and procedures already developed and documented and will include variations of this technology as seems appropriate.

Stereograms: To establish an expertise in photo interpretation and to serve as a future training tool, stereograms were constructed representing insofar as possible the range of cover types, density and broad site/productivity levels. Bernstein (1968) defines stereograms as "...mounted stereographic pairs of photographs which present three-dimensional views of known conditions or objects of interest". Normally, relationships established by the stereogram are applied to other areas of similar composition.

The stereograms were constructed from color aerial photographs flown at an average scale of 1:15,840. Choosing by observation the most representative area for the conditions being depicted, a cluster sample was taken in a 16 hectare (40 acre) block as a primary sample unit within which 16 sample points were systematically distributed. Data collected from these points describe in detail the characteristics of the conditions represented. Figure 5a and 5b illustrate the stereogram format and the included detail information as gathered from

the sample block. Figure 5c illustrates the ground representation of this stereogram. For narrow or small areas of significance, where the establishment of a 16 hectare block was not possible, smaller areas were delineated and sampled accordingly; figure 6, a-c.

Sample Design: The sampling scheme for Phase I might be best called a stratified double sample design. Stratification is used to break down a basically heterogeneous forest into more uniform strata in an attempt to reduce the variation within the forest subdivisions; Husch, et al (1972). A broader range of variation was allowed within the strata than would be allowed within an Operating Area; however, the strata did reflect generalized areas of similar cover type, age and density classes. Work to date has occurred only in the Pensacola area, and for this area, five strata were recognized:

1. Merchantable Natural Pine[3/]
2. Regenerated Merchantable Pine, $\geq$18 years old
3. Regenerated Merchantable Pine, $\leq$18 years old
4. Merchantable Pine-Hardwood/Hardwood
5. Non-stocked, Understocked, Non-Productive, Premerchantable.

Upon completion of the stratification process, a sample point network was installed for double sampling. Double sampling involves the estimation of a secondary variable X in a first phase and the subsample of a related primary variable Y in a second phase. Generally such an approach is used where the obtaining of the variable X is relatively inexpensive with relation to obtaining the variable Y. Photo/ground sampling procedures are a classic example of the double sampling technique. In this case, X is a photo estimate of stand density derived from the evaluation of the photograph's tonal and textural attributes. Photo estimates are relatively inexpensive. The primary variable Y is the measured stand density, in terms of volume, on the ground based upon individual tree estimates. Ground samples are relatively expensive.

Since tree volumes are of concern, double sampling is extended to a final stage wherein the individual tree volume estimate becomes X, and the measure of the tree's volume becomes Y. Precise individual tree measurements are secured using a Barr & Stroud Dendrometer. Both phases of a double sample are mutually dependent since the measurements in the second phase are taken as a portion of the sample in the first phase. It is vital, therefore, to make sure the actual selected photo location is occupied on the ground, and that individually measured trees are included in those estimates.

The method of selecting Y in the second stage, is one of unequal probability, wherein the probability of an item being selected is proportional to some predictive quantity, hopefully correlated with the values of interest such as volume.

3/ Merchantability is an arbitrary size limit associated with stem diameter as measured 1.37 meters (4.5 feet) above the ground (diameter breast height, DBH). Minimum merchantability criteria is 12.7 cm (5.0 inches at DBH) for all species.

Such a procedure is known as 3P sampling; Grosenbaugh (1971). The measured values of Y taken as a light second phase sample will be used to correct the estimated variable X, obtained from a heavy first phase sample. Such a correction takes the form of a correction regression made between X and Y. The measure of efficiency of double sampling is the degree of correlation achieved between X and Y. Such a correlation can be expressed as a coefficient of simple correlation of the form:

$$r = \sqrt{1 - \frac{SX^2}{\sigma Y^2}}$$

where: r = coefficient of simple correlation
SX^2 = standard deviation of the difference between X and Y
σY^2 = standard deviation of the sample population

At each sample point, a multi-stage sample cluster was established consisting of four subsample points located one chain[4/] from the center point in cardinal directions. The clusters sampled a primary unit of .4 hectares (one acre) in size. This rather large plot size is used because it permits the interpreter to average minor variation in stand structure. Also, this provides a larger "target" for the field crew. The exact correspondence between the areas estimated on the photo and on the ground is considered essential in establishing a high correlation between X and Y.

Photo estimates have been made on all primary sample units and field measurements are now in progress.

Upon completion of this work, an Administrative Unit/Operating Area overlay will be superimposed and through further double sampling with photo interpretation, strata volumes will be distributed to the associated Operating Areas. The interpreter will have the benefit of the stratified results in terms of averages and ranges of the quantities of interest.

Possibility of Success: The idea of cruising timber from aerial photographs is not new, it has just been overlooked in many areas. The benefits in efficiency were pointed out in the late 1940's and early '50's; Moessner and Jensen (1951). Elaborate aerial volume tables were published; Avery and Myhre (1959), to be followed by forest typing techniques, Avery (1960). It is probably safe to say, with few exceptions, that more serious photo interpretive efforts were made in the South in these early years than has been done since. Currently aerial photographs are used primarily as locational and mapping tools.

It is felt that during a period where knowledge of the forest was slight and access difficult, aerial interpretation was relied on out of necessity. As

---

4/ Gunters chain, a standard forestry unit of linear measure.
1 chain = 66 feet = 20 meters.

management intensified, information needs transcended that available from the then current photogrammetric techniques. Several things have occurred since to indicate this may no longer be the case.

1. The high quality of photo products available both in color and color infra-red.

2. The change of the primary unit of management from a rectangular heterogeneous block to relatively uniform biological entities.

3. The existence of a substantial base of information built upon prior knowledge.

4. Development of more efficient sampling techniques.

5. The availability of high quality, relatively inexpensive photo interpretive equipment.

In light of the above, it is felt that the probability of establishing an information base suitable for management requirements through a photo/ground double sampling procedure, alleviating the ground sampling effort, is encouraging.

II. Multi-Spectral Digital Data Analysis

Hypothesis.- Given adequate correlative capabilities from Phase I, that similar correlation can be established between ultra-small scale imagery (as may be secured from LANDSAT or other airborne platforms), and conventional middle to large scale aerial photographs; negating the necessity of correlating such small scale imagery directly to ground sample units.

Objectives.- The overall objective of this phase of study is to evaluate the usability of multi-spectral, small scale digitized data as a viable data source in forest data acquisition, such that these techniques become a significant contributor to a multi-level sampling system.

A coordinate objective will be to ascertain the applicability of existing ADP software in achieving the analysis and output necessary and to determine if such software packages can be modified and streamlined for more general use with existing hardware, as might be available to any user group.

In addition to the broad objective statement made for this phase, it would seem that several ancillary objectives, not so dependent on the success of Phase I, could be reasonably expected, and would include·

1. Broad cover type identification and delineation.

2. Separability of various forest density classifications.

3. Geometric resolution.

4. Changing land use patterns.

Procedures.- The procedures to be followed in Phase II are largely dependent upon Phase I. It is fully expected that LANDSAT data will be used because of its availability and reasonable cost. It is further anticipated that these data will be evaluated in both the multi-band photo interpretive mode and in the multi-spectral digital mode.

With the data source available, there will be a need to establish the system of software packages to be used, if indeed such exist, to meet our objectives. It is strongly felt that considerable commitment must be associated with this phase, and possibly a consortium may be the most logical approach to the problem. With institutional representation as part of such a cooperative approach, the other participating members could be from interested companies or as inter-divisional participation within our own organization. The commitment might well include sponsorship of graduate assistantships at various levels. In any case, the procedures followed at this stage of the investigation are not well established, and often may be just hints of possible directions to pursue.

Known classification techniques will be investigated to ascertain the level of precision possible in separating the many densities involved. Assuming classification can progress beyond broad forest types of a level 1 classification; Anderson, et al (1972), is the geometric fidelity sound enough to establish property boundaries given digitized maps? If this capability is possible, then how well can density classifications be separated; and can there be a correlation established between these density levels (X) and those levels as established on aerial photographs (Y)?

Possibility of Success.- The procedures to be followed and the following discussion are, of course, largely conjecture. Accordingly, the degree of success of this phase is speculative; however, there are some indications of at least partial success in most areas. At the outset, forestry applications are well suited to ultra-small scale imagery, due to the non-critical nature of absolute resolution. Forestry operations, in general, occur over broad areas, usually at least 8 hectares (20 acres) and generally from 40-120 hectares in size (100-300 acres). Given reasonable geometric fidelity, most of these areas could be readily identifiable.

It is true that digitized data lack the tonal, textural and geometric characteristics of a photograph, but hopefully the multi-spectral aspects of the imagery will overcome some of these disadvantages and will add some advantages of their own. Multi-spectral data, in contrast to photographs, can take advantage of spectral "signature" characteristics. Analyses have been successful in delineating several land and vegetative classes, and have aided in differentiating areas of contrasting densities; Yost, et al (1971).

Finally, it should be pointed out, that this study is not and cannot be dependent on satellite imagery, LANDSAT or any other, simply because there is no guarantee of a data continuum from this source. Rather, efforts are being directed toward multi-spectral digital analysis applicable to data from whatever source. It seems fair to expect success at least in generalized terms especially in the area of the ancillary objectives, and the possibility of success in achieving the primary objectives is too provocative to overlook.

III. A Semi-Automated Multi-Level Sampling System

Hypothesis.- Given reasonable success in Phase I and Phase II, a semi-automated multi-level sampling system is achievable in which data acquired at several scales can be integrated with digitized ground truth and geometric area boundaries to provide an updated, computer oriented data bank of information at precision levels commensurate with the needs of management.

Objectives.- The overall objective of this third and final stage is to integrate the salient features of Phase I and II into a functional data acquisition system, semi-automated and compatible with the long range planning data base required.

Procedures.- Procedures at this point in time are largely uncertain since implementation of Phase III is still somewhat in the future. Multi-level sampling as used in the context of this paper refers to a sampling scheme where data are collected at various levels of precision. At the broadest level estimates are made, hopefully related to other variables measured more precisely at some lower level, with these variable estimates in turn, being related to variables measured at still another lower and more precise level. In effect, a multi-level sample is merely a system of inter-related double samples. The basic multi-level approach as put forward in the past establishes a broad generalized data base from digitized ultra-small scale imagery, Aldrich (1971). From this base, subsample blocks are superimposed as a basis for an underflight estimate; finally, strips of extremely large scale photography are flown upon which ground sampling takes place utilizing some form of unequal probability sampling much like the 3P/dendrometry procedures outlined by Grosenbaugh. From the ground sample, data are expanded to the strip and then to the block and finally to the entire area. Although Aldrich had mixed results in this study, the concept was statistically sound and with some more refinements could be a workable approach. Unfortunately, such an approach would necessarily ignore the Operating Area, or any other small subdivision.

Because of the Operating Area's central role as a primary inventory, projection and management unit, classical multi-level sampling procedures must be modified to meet our basic objectives. The modification involves the tie between the Operating Area and the other levels of sampling units. For this reason, the establishment of a sound correlation between photo estimated average quantities and average quantities as measured for an Operating Area, is essential for success of the proposed system. Such a correlation would provide the link between a standard multi-level sampling procedure and the Operating Area. Such a link, then, would allow for the exploitation of the multi-level results at the ownership, district or mill region level without compromising the integrity of the Operating Area.

Possibility of Success.- If Phase I and II are successful at least to the degree of establishing the multi-level concept as a feasible option, success in Phase III is assured, at least in theory. The principal and most difficult task of Phase III, is to relate the multi-level approach to an information system, operationally executable, economically feasible, with results that enjoy the confidence of management. From a practical standpoint, this task represents the bottom line of the entire project.

DISCUSSION

Operational considerations in adapting any new technology are always a challenge. New ideas must be presented with gusto in almost a revolutionary context just to

attract attention. Once given the sanction to proceed, however, an evolutionary philosophy must be adopted to assure success, or at least to avoid disaster; witness the development of the computer sciences in the '50's and '60's.

Remote sensing as a relatively new technology, and its integration into an ongoing data acquisition system, is no exception to the above. It is vitally important not to be "carried away" by the dazzling possibilities and to look toward this technology as a tool and not a panacea to all data acquisition problems. It was felt that stepwise progression toward a multi-level sampling system was the logical approach to the problem, where expertise could be built on past experience.

Because of the nature of a modular approach to the problem, the objectives as stated for the various stages and the procedures outlined are subject to change as experience dictates. Although the overall complex of the problem solution may change, there seems to be a reasonable chance of at least a partial solution based upon work already done.

Remotely sensed ultra-small scale imagery is being viewed as one of many data acquisition tools which collectively establish a data base far more comprehensive than any one method could singly provide.

LITERATURE CITED

1. Aldrich, Robert C. 1971. Space Photos for Land Use and Forestry, Photogrammetric Engineering. Vol. 37, No. 4.

2. Anderson, James R., Ernes E. Hardy and John T. Roach. 1972. A Land Use Classification System for Use With Remote Sensor Data. Geological Survey Circular 671.

3. Avery, Gene and David Myhre. 1959. Composite Aerial Volume Table for Southern Arkansas. Occasional Paper 172, USDA Southern Forest Experiment Station, New Orleans, Louisiana.

4. _____. 1960. Identifying Southern Forest Types on Aerial Photographs. Station Paper 112, USDA Southeastern Forest Experiment Station, Ashville, North Carolina.

5. _____. 1960. Foresters Guide to Aerial Photo Interpretation. Occasional Paper 156, USDA Southern Forest Experiment Station, New Orleans, LA.

6. Bernstein, David A. 1968. Constructing Stereograms. Photogrammetric Engineering, Vol. 34, No. 4.

7. Grosenbaugh, L. R. 1971. Forest Dendrometry of Multistage 3-P Samples. STX1-11-71; USDA Forest Service.

8. Husch, B., C. E. Miller and T. W. Beers. 1972. Forest Mensuration. The Ronald Press Company, New York, NY.

9. Moessner, Karl E., and Chester E. Jensen. 1951. Timber Cruising on Aerial Photos. Technical Paper No. 126. USDA Central States Forest Experiment Station, Columbus, Ohio.

10. Yost, Edward, Sondra Wenderoth and Robert Anderson. 1971. Multi-spectral Remote Sensing of Agricultural and Forestry Test Sites. American Society of Photogrammetry. Third Biennial Workshop Color Aerial Photography in the Plant Sciences and Related Fields.

TABLE I.- ST. REGIS TIMBERLANDS -

HECTARES BY TYPE OF HOLDING, BY DIVISION

Location	Thousands of Hectares		
	Owned	Controlled	Total
Northern Timberlands	497 (1,243)[a]	5 (12)	502 (1,255)
Southern Timberlands	312 (782)	380 (949)	686 (1,716)
Northwest Timberlands	196 (489)	66 (164)	262 (653)
Canadian Timberlands		765 (1,912)	765 (1,912)
Totals	1,006 (2,514)	1,215 (3,037)	2,221 (5,551)

TABLE II.- SOUTHERN TIMBERLANDS DIVISION

HECTARES BY TYPE HOLDING, REGION AND STATE
JANUARY 1, 1975

State	Hectares		
	Owned	Controlled	Total
Jacksonville Region			
Alabama		286 (715)	286 (715)
Florida	52,152 (130,380)[a]	62,653 (156,633)	114,805 (287,013)
Georgia	27,257 (68,142)	148,383 (370,958)	175,640 (439,100)
Total Region	79,409 (198,522)	211,322 (528,306)	290,731 (726,828)
Pensacola Region			
Alabama	38,676 (96,6[illegible])	65,946 (164,864)	104,622 (261,555)
Florida	103,920 (259,799)	31,583 (78,958)	135,500 (338,751)
Total Region	142,596 (356,490)	97,529 (243,822)	240,122 (600,306)
Mississippi Region			
Louisiana	1,520 (3,799)	3,392 (8,480)	4,912 (12,279)
Mississippi	79,949 (199,873)	70,800 (177,000)	150,749 (376,873)
Total Region	81,469 (203,672)	74,192 (185,480)	155,661 (389,152)
Total Division	303,474 (758,684)	383,041 (957,602)	686,514 (1,716,286)

[a] Figures in parenthesis represent thousands of acres.

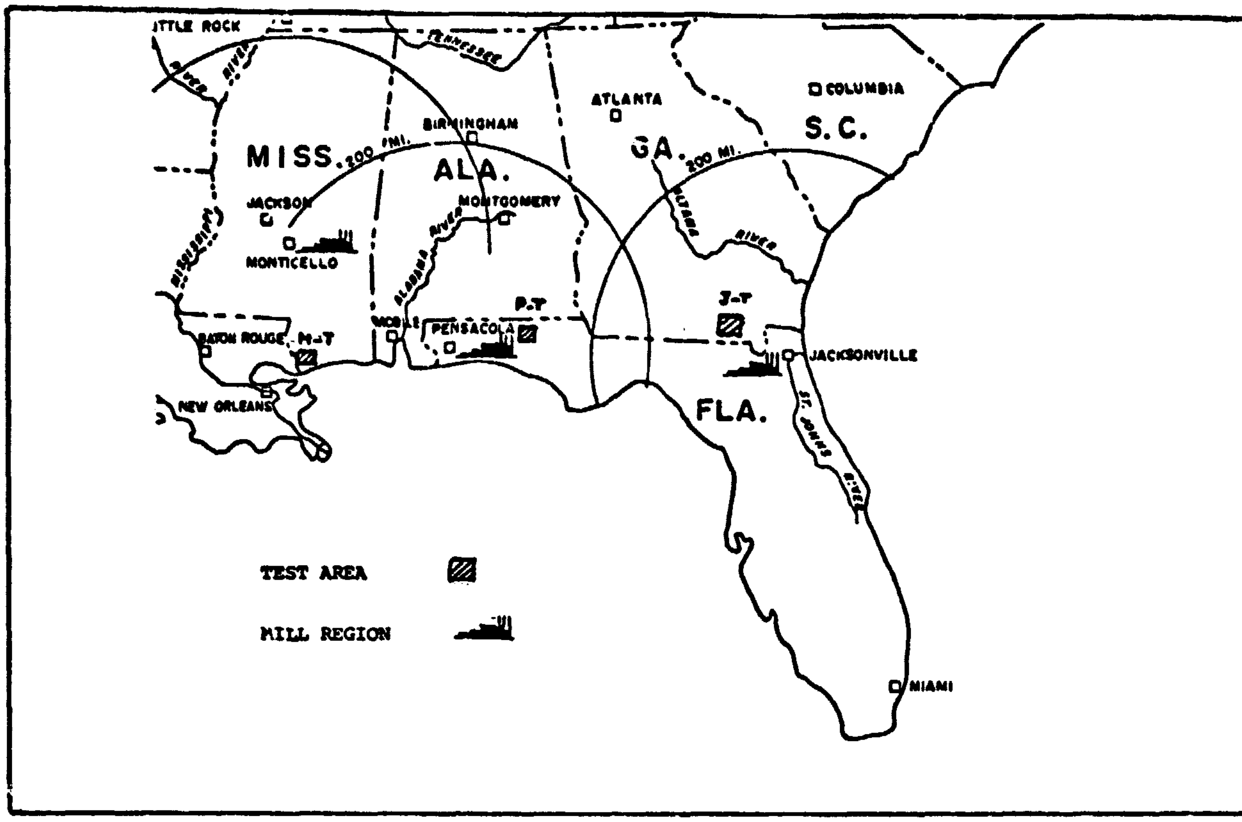


Figure 1 - St. Regis, Southern Timberlands Mill Locations and Remote Sensing Test Areas.

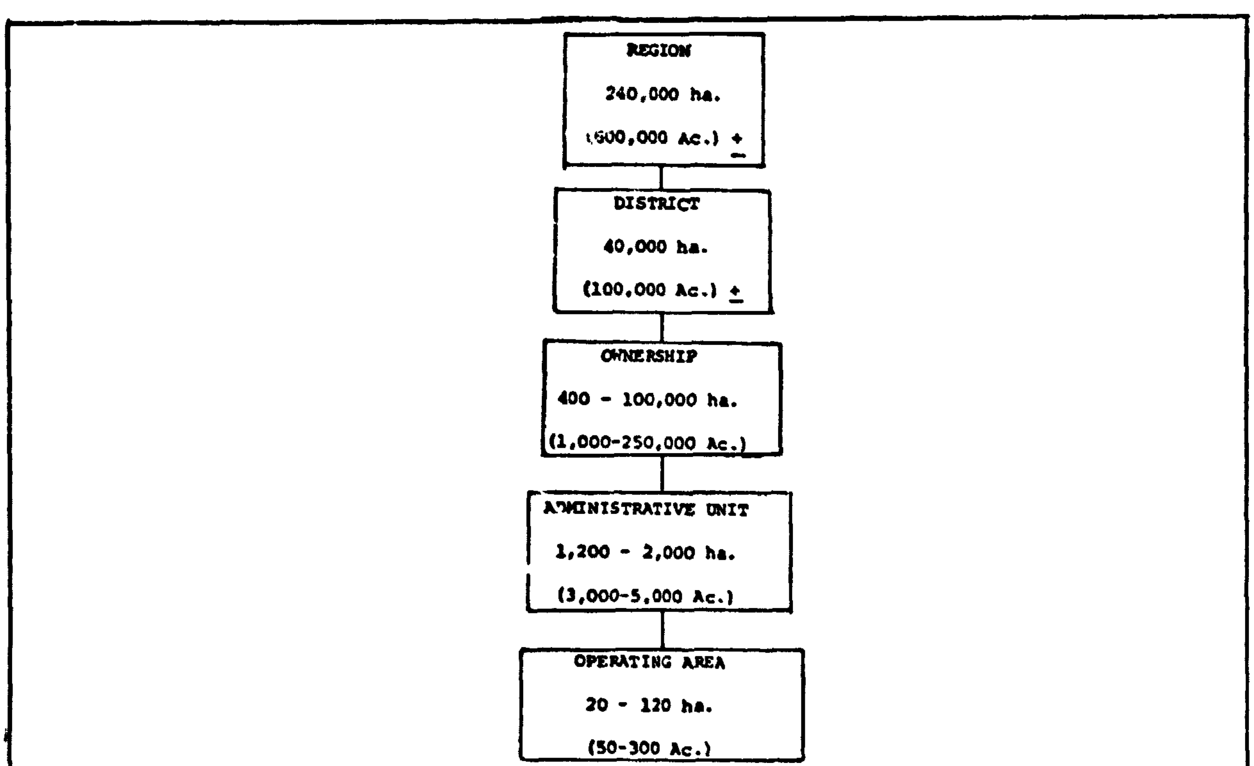


Figure 2 - St. Regis Southern Timberlands Mill Region Administrative Hierarchy

ST. REGIS PAPER COMPANY PERMANENT GROWTH SAMPLE
FIELD TALLY SHEET

State	County	T	R	S	Crew

-1- Plot No.	-2- Date	-3- Mill Region	-4- Dist.	-5- Owner.	-6- A.U.	-7- O.A.
1 2 3 4	5 6 7 8	9	10 11	12 13 14	15 16 17	18 19

Pl. Yr.	District	No. Trees (Surviving)

-8- For. Type	-9- For. Topo	-10- Size Class	-11- Age Cl.	-12- Ht. Cl.
20 21	22 23	24	25 26	27 28 29

P.B.____________________

Dist.____Chains

Bearing _____

Tree No.	Dist. Ft.	Bearing

-13- Site	-14- Gr. Cvr.	-15- Pine Rep.	-16- Hdwd. Rep.	-17- Cyp. Rep.
30 31 32	33 34	35 36	37 38	39 40

-18- Density (Crn. Cvr.)	-19- Stand Cond.	-20- Past Mgt.	-21- Injury	-22- Slope	-23- Asp.	-24- Growth
41 42	43 44	45 46	47 48	49 50	51	52

25 Tree No. 20 21 22	26 Species 23 24	27 DBH 25 26 27	28 Crown Cl. 28	29 Crown Diam. 29 30	30 Crown Lngth. 31 32	31 Prod 33	32 Vig 34	33 CFT Soundness 35 36 37	34 Saw Soundness 38 39 40	35 Total Ht. 41 42 43	36 Ht. to 4" Top 44 45 46	37 Ht. to 8" Top 47 48 49	38 Mert 50	39 Rrr 51	40 Gre 52

OAI FIELD TALLY SHEET

TRACT: ________________ DATE: __________ CREW: __________

DISTRICT	OWNER	AD.UNIT	O.A.	POINT NO.

ST	TOWNSHIP	RANGE	SEC	SLOPE	AS	SR	TYPE	TOPO	AGE	SI/50	CND	ORG

SITE INDICATOR TREE

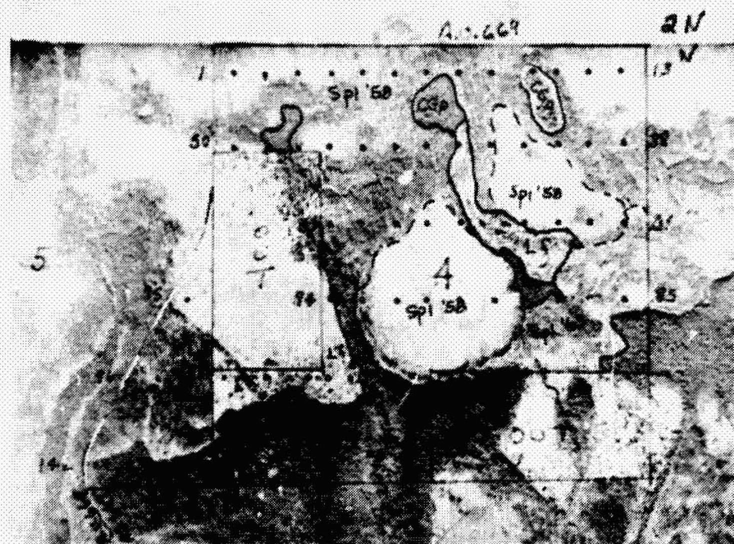
SPEC	DBH	HT.	AGE

PINE PRE-MERCHANTABLE					HARDWOOD PRE-MERCHANTABLE					CYPRESS PRE-MERCHANTABLE				
R	1	2	3	4	R	1	2	3	4	R	1	2	3	4

TREE DATA

NO	SPECIES	DBH	CR	VG	PRO	UTL	INJ	PULPWOOD HEIGHT	PULPWOOD SOUNDNESS	SAWTIMBER HEIGHT	SAWTIMBER SOUNDNESS	QUALITY SOUNDNESS	OTH
1													
2													
3													

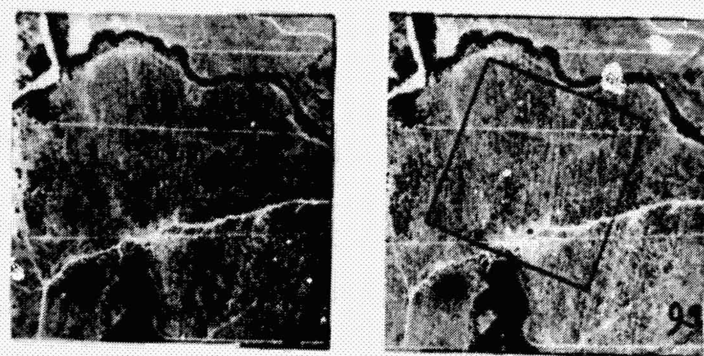
Figure 3 - St. Regis Data Acquisition Field Tally Sheet Forms



KEY:

Out	property not owned or controlled
Spl	Slash pine plantation and date of planting
PHb	Pine/hardwood branch
CGp	Cypress gum pond
Lf	Longleaf flat

Figure 4 - An administrative unit with included operating areas and ground sample grid.



(a)

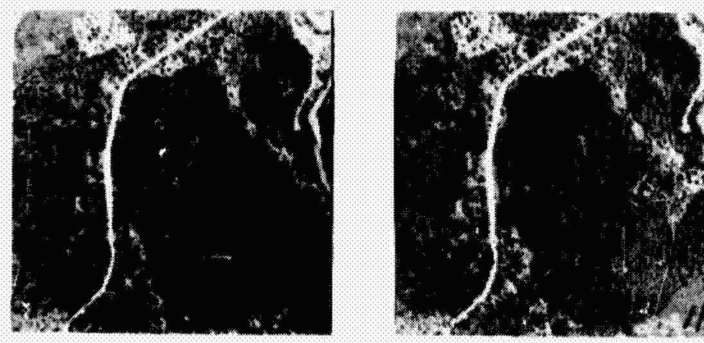
BLOCK NO. P-9

Condition		Structure	
For. Type	PLANTED SLASH	Cords/Acre	
Topo.	UPLAND	Pine	—
Ground Cover		Hardwood	—
SHORT GRASS	55 %	Av. Merch. Ht.	—
WIRE GRASS	20 %	PM Pine S/A	
		1-2" 280	3-4" 150
Site Q %	57		
Soil Color	03	Crown Closure	25% %
Age	6	C. V.	23 %

(b)

(c)

Figure 5 - A standard stereogram format showing: (a) a stereo pair with primary sample unit layout; (b) associated statistical data; (c) ground representation.

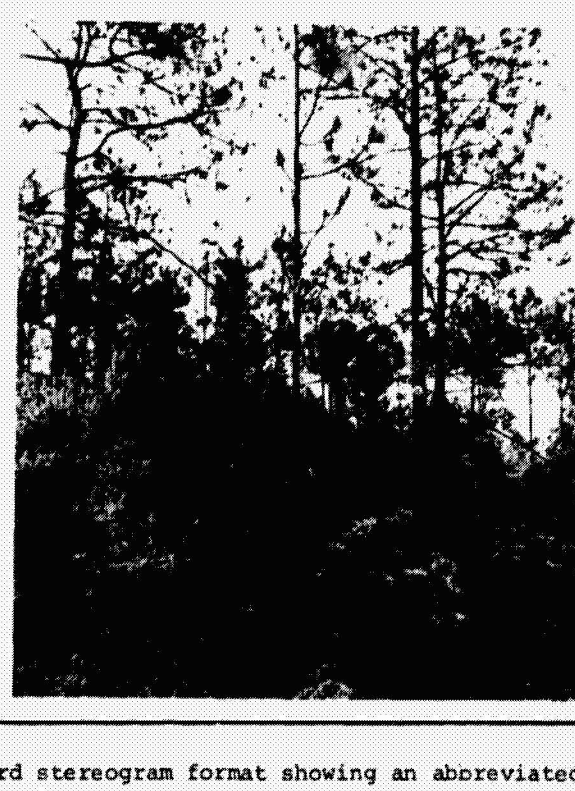


(a)

BLOCK NO. P-11

Condition		Structure	
For. Type	SLASH - HWD	Cords/Acre	
Topo.	BAY	Pine	16.0
Ground Cover		Hardwood	4.5
BRUSH	85 %	Av. Merch. Ht.	50
LITTER	10 %	PM Pine S/A	
		1-2"	✓
		3-4"	✓
Site I	80		
Soil Color	✓	Crown Closure	55 %
Age	95	C. V.	70 %

(b)



(c)

Figure 6 - A standard stereogram format showing an abbreviated sample unit layout showing: (a) a stereo pair with primary sample unit layout; (b) associated statistical data; (c) ground representation.

TIMBER TYPE SEPARABILITY IN SOUTHL STERN UNITED STATES ON LANDSAT-1 MSS DATA* A-11

By E. P. Kan and R. D. Dillman, Lockheed Electronics Company, Inc.
Houston, Texas

N76-17479

ABSTRACT

A quantitative, computer-aided study was made on the spectral separability of timber types and condition classes in the Southeastern United States, using LANDSAT-1 multispectral scanner data. Conclusions were obtained on accuracies at different levels of mapping detail and the choice of parameters affecting mapping accuracies, such as spectral bands, number of bands, and seasons of data.

It was concluded that LANDSAT-1 could be used effectively to discriminate the gross forest features of softwood, hardwood, and regeneration. The only significant detectable age difference would be between an established forest versus a young (or denuded) forest, i.e., regeneration. The red or near infrared bands would be better for discrimination; phenological early and late spring data would be better than winter (summer and autumn data were not available for analysis). And a temporal analysis would be superior to single-season analysis. Lastly, two spectral bands would be most cost effective for computer analysis.

The study site, Sam Houston National Forest of East Texas, is a typical forest in the Flatwoods Zone, Southern Region, U. S. Forest Service. The widely accepted computer scheme of training-field, maximum likelihood-classifier was employed, while cross-classification accuracies and divergence measures were computed to evaluate timber type separability.

1.0 INTRODUCTION

This study was undertaken to determine the feasibility of mapping timber types and condition classes in the Southeastern United States using Land Satellite (LANDSAT-1, formerly Earth Resources Technology Satellite, ERTS-1) multispectral scanner (MSS) data via computer-aided analysis. Timber types refer to stand composition by dominant species, and condition classes refer to age, size, health, and adequacy of stocking. To this end, three objectives were pursued:

- To quantitatively determine the spectral separability between timber types and condition classes, and additionally between the general classes of merchantable timber which consist of sawtimber, poletimber, and regeneration softwood stands.

*The material of this paper was developed under NASA Contract NAS 9-12200 and prepared for the Earth Observations Division, NASA, Johnson Space Center, Houston, Texas.

 PRECEDING PAGE BLANK NOT FILMED

- To determine the optimal spectral bands and seasons of MSS data for maximum separability between timber types and condition classes

- To determine the effects on classification accuracies because of variations in the number of spectral bands

Such a study is essential to computer-aided remote sensing applications on timber resource inventories concerned with mapping and volume estimation. The mapping accuracy, mapping levels, sensor spectral band coverages, seasons of data acquisition, and number of bands used in analysis are important design criteria in these inventories. An optimally designed timber resource inventory using remote sensing data, from satellites and aircraft, in conjunction with ground surveys would provide a most efficient, timely, accurate, and economical solution to many forest management problems. For example, studies by Aldrich (1971) and Colwell (1973) have proved the efficient use of a multistage sampling scheme to estimate timber volume on a forest-wide basis.

The present study determined whether or not satellite MSS data such as that of LANDSAT-1 could be used at or beyond the mapping level of softwood, hardwood, mixed softwood-hardwood, and regeneration, the four categories constituting forest land. (See hierarchy levels in section 2.2.) Also, this study established the feasibility of discriminating merchantability age classes by LANDSAT-1, i.e., discrimination between sawtimber, poletimber, and regeneration stands of softwood. These conclusions were derived from analyzing a typical forest in the Southeastern United States, as represented by the Sam Houston National Forest of East Texas.

A number of past studies have been carried out on similar subjects, but not to the same extent of details in mapping and not to the same amount of quantification of separability. In the report by Heller et al. (1974), investigators reported on the use of October LANDSAT-1 MSS data and computer classification techniques in mapping level II land use classes in Georgia. Level II included pine and hardwood classes and were identified with accuracies ranging from 42 to 81 percent. Erb (1974) reported the analysis of August 1972 LANDSAT-1 data on the Sam Houston National Forest of Texas, breaking forest land down into hardwood versus pine with accuracies as high as 91 percent. Aircraft MSS data have also been analyzed with the purpose of identifying forest land use classes. Weber (1972) reported processing a November data set over Atlanta, Georgia, and found that spectral bands very similar to band 7 (0.8-1.1 micron) and band 5 (0.6-0.7 micron) of LANDSAT-1 were the third and fourth best channels after the infrared band (1.5-1.8 micron) and thermal band (9.3-11.5 micron) for separability of forest classes. Accuracies for classification of pine and hardwoods ranged from 20 to 80 percent.

The present study is part of the Forestry Applications Exploratory Studies Project, which is conducted by the Earth Observations Division at the Lyndon B. Johnson Space Center of the National Aeronautics and Space Administration and by the Southern Region of the Forest Service, U. S. Department of Agriculture. Project details can be found in Anon. (1974).

2.0 STUDY SITE AND FEATURES

2.1 Site Description

The study site is the Conroe Unit, Raven District of Sam Houston National Forest, located 90 kilometers north of Houston, Texas (figure 1). This forest is in the "East Texas Piney Woods" or "Flatwoods," which is the heavily forested portion of East Texas. The Conroe Unit is within the southern Gulf Coastal Plain, and the overall area slopes to the southeast at 1.5 meters per kilometer. Slopes are generally between 3 and 7 percent; elevation differences between stream bottoms and ridge tops are usually no more than 25 meters.

The 28,500 hectares of the Conroe Unit consist of approximately 10 percent shortleaf pine (*Pinus echinata* Mill.) on the ridges and upper slopes, 75 percent loblolly pine (*Pinus taeda* L.) and hardwoods on the lower slopes, 10 percent hardwoods in the drainage ways, and 4 percent regeneration areas. The remaining 1 percent is made up of openings such as pipelines or oil well sites. The most common hardwood types are mixed oaks – laurel oak (*Quercus laurifolia* Michx.) and willow oak (*Quercus phellos* L.), and gums and oaks – sweetgum (*Liquidambar styraciflua* L.), nuttal oak (*Quercus nutalli* Palmer), and willow oak.

2.2 Analysis Levels

A five-level hierarchy of land features was used for this study (table I). The terminology and structure of the hierarchy resulted from modifications of those from the Society of American Foresters (Ford-Robertson, 1971; Anon., 1974), The Forest Survey (Sternitzke, 1967), and the Geological Survey (Anderson et al., 1972). The definitions of levels I and II features are adopted as follows:

Forestland -	land of 0.4 hectares or more in size supporting a stand of trees whose crowns cover more than 10 percent of the area
Softwood -	gymnosperms, generally having evergreen and needle foliage; a softwood stand consists of more than 50 percent pine in the overstory.
Hardwood -	angiosperms, generally having broadleaved and deciduous foliage; a hardwood stand consists of less than 25 percent pine in the overstory
Mixed softwood-hardwood -	a stand of mixed softwood-hardwood consisting of 25 to 50 percent pine and the rest hardwood
Regeneration area -	cutover, burned, or otherwise denuded forestland in process of being reclaimed by a young forest.

The class "regeneration" in level II was considered appropriate in this computer-aided remote sensing application, since regeneration has spectral characteristics known to be distinct from established forest stands. Also, it was considered impossible to discriminate among shortleaf regeneration,

loblolly regeneration, and hardwood regeneration. The breakdown under regeneration into seedling-sapling or nonstocked is at level V.

Levels III, IV, and V are traditional breakdown and represent levels of detail usually mapped by ground survey or photointerpretation. The special level "general age class" was created to study the condition classes of softwoods collectively, i.e., sawtimber, poletimber, and regeneration areas. The identification of these general classes, as opposed to the more detailed level IV classes, has mercantile and management import. The limited amount of hardwood sites in the study area did not allow this study to analyze hardwood sawtimber, poletimber, and regeneration separability.

3.0 TECHNICAL APPROACH

The overall approach taken in this study is the "training-field classification/analysis" process used in computer systems such as LARSYS (Phillips, 1973), RECOG (Ells et al., 1972), and ERIPS (Anon., 1973). This approach essentially consists of (1) the acquisition of spectral signatures of land features by locating "training fields" of these features on MSS data and computation of their statistics; (2) searching for optimal set of channels for classification through calculation of some mathematical distances, e.g., divergence (Marill and Green, 1963) or probability of correct classification (PCC) (Anderson, 1958); and (3) computer classification, e.g., using a maximum likelihood classifier which assigns to an unknown data pixel (picture element in MSS data) a most likely class association from all the possible training classes. A training class means land feature on which training field statistics are available. Through this process, timber type separability information will be obtained via the two mathematical measures of divergence and PCC. (See section 3.2 for details.)

Figure 2 is a schematic flow diagram of the analysis procedures followed in this study. Three LANDSAT-1 data sets were checked for data quality before they were registered and composed to form one 11-channel data set. The registration was performed image-to-image and to the corresponding longitude and latitude locations. Since each individual-date data set has four MSS channels, the composition of data sets resulted in a 12-channel data set with the ordering of the channels and their spectral coverages tabulated in table II; however, the last channel of the May data set was too noisy, and thus omitted from analysis, hence an 11-channel data set.

Random training fields of the level V forest features (table I) were selected and their coordinates recorded on the MSS data. The same locations applied to all three dates because the three data sets had been registered to one another. By straightforward aggregation, training fields for all hierarchy levels were compiled. At each level, divergence calculations were made, compiled, tabulated, and analyzed. Also class pairs were classified, a pair at a time, producing pairwise correct classification accuracies. The average of these were then calculated, tabulated, and analyzed. Additionally, all class statistics were used simultaneously to classify all the selected random test fields, producing overall classification accuracies. (See section 4.0 for examples.)

3.1 LANDSAT-1 Data

The LANDSAT-1 frames over the study site were used for analysis and covered three distinctive phenological dates in the Southeastern United States. These dates covered winter (I.D. 1127-16253, November 27, 1973), early spring (I.D. 1217-16254, February 25, 1973), and late spring (I.D. 1289-16254, May 8, 1973). Summer and autumn data were not available for analysis. These three data sets were registered and composed to form an 11-channel (12 less 1 because of poor quality) temporal data set of a size roughly 500 scan lines and 600 pixels per line. The ordering and spectral coverages of these temporal channels are listed in table II. A black-and-white rendition of channel 6 (February band 2) is shown in figure 3.

Because of the small spatial resolution of LANDSAT-1 MSS data (at 80×80 meters per pixel after registration), the sizes of training fields and test fields were constrained to be no more than 5×5 pixels. Hardwood features usually called for narrower and smaller fields. In this study, the number of training fields and test fields had been chosen roughly proportional to their occurrence in the study site. These fields constituted roughly 1 percent of the study site.

3.2 Separability Measures: Divergence and PCC

Two mathematical measures were used to quantify the spectral separability between timber types: (1) the divergence measure, J and (2) the probability of correct classification, PCC. (Marill and Green, 1963; Anderson, 1958; and Chang, 1971)

The divergence measure is an approximate measure for separability, while the PCC measure is truly the separability measure. However, PCC is difficult, if not impossible to calculate except by straightforward estimation via computer classification which provides classification accuracy measures. On the other hand, the divergence measure can be algorithmically computed based on the usual statistical assumption of normality. In this study, the divergence measure and the classification accuracy measure were jointly calculated where an increase in values of either measure was construed as an increase in separability

The definitions of the divergence $J(C_1,C_2)$ and the pairwise correct classification accuracy $PCCA(C_1,C_2)$ between the two statistical classes C_1 and C_2 are as follows:

$$J(C_1,C_2) = \tfrac{1}{2}tr\left[\left[S_1 - S_2\right]\left[S_2^{-1} - S_1^{-1}\right]\right] + \tfrac{1}{2}\left[M_1 - M_2\right]^T\left[S_1^{-1} + S_2^{-1}\right]\left[M_1 - M_2\right]$$

where M_1, S_1 are the mean vector and covariance matrix of C_1, and M_2, S_2 are those for C_2, tr stands for the trace operation on matrices, and T stands for the transpose operation on matrices.

$$PCCA(C_1,C_2) = \tfrac{1}{2}PCC(C_1) + \tfrac{1}{2}PCC(C_2)$$

where $PCC(C_1)$ and $PCC(C_2)$ are obtained by a two-class classification between C_1 and C_2, and where

$$PCC(C_1) = (\text{number of pixels of } C_1 \text{ correctly classified as from } C_1)$$
$$\div (\text{number of pixels of } C_1)$$

and $PCC(C_2)$ is defined similarly.

When more than two classes are involved in classification, the overall average pairwise correct classification can be calculated as the average of the n(n-1)/2 pairwise measures, obtained from n(n-1)/2 possible pairs from the n classes (n>2).

4.0 ANALYSIS OF DATA PROCESSING RESULTS

All the data processing was performed at the Johnson Space Center, NASA, and on the Earth Resources Interactive Processing System (ERIPS) which is an interactive computer system developed at the center for remote sensing applications. This system has the capability of training field classification analysis as described in section 3.0. However, in this application on ERIPS, the transformed divergence J' was used instead of the divergence J defined in section 3.2, where J'=999 (1-exp(-J/16)). J' and J are equivalent (Swain, 1973); any conclusion drawn from J' computations applies to J computations and vice versa. Without further complication, the following sections will abuse the notation, using J to denote the transformed divergence and using divergence to mean transformed divergence.

4.1 Spectral Signature Plots

Before presenting the quantitative separability results in the next three sections, a most effective qualitative analysis could be made by plotting the spectral signatures of all the forest features. A spectral signature plot means the graph of the statistical mean data values versus spectral channel. The mean values were obtained from analyzing training fields.

Figure 4 is such a plot for all the 10 level V (the most detailed level) forest features. Four groups of features seem readily distinguishable and are thus presented in the figure: (1) regeneration, nonstocked; (2) regeneration, seedling and sapling; (3) hardwood, immature sawtimber; and (4) softwood and mixed softwood-hardwood, comprising loblolly and shortleaf, sawtimber and poletimber, mature and immature (table I).

In qualitative terms, then, only level II forest features can be distinguished from one another, except for the mixed softwood-hardwood feature in this level. The more detailed detection levels in levels III, IV, and V seem too much to ask of the LANDSAT-1 MSS sensor. Additionally, temporal channels 6 and 11 show widest spread of data values in the above mentioned four groups of signatures, indicating that these two channels would likely be the best two channels for discrimination of level II forest features (except for the mixed feature). Determination of the truly best channels involves consideration of the spread of data values about the mean value of all the features. Figure 4 does not indicate this kind of statistical variation, and only an analysis as in section 4.3 will give the most definitive answers.

These signatures were analyzed from a total of 25 training fields of the 10 level V forest features.

4.2 Pairwise Separability of Forest Features

The 25 level V training fields selected earlier were aggregated into 10 level V training classes, seven level IV training classes, five level III training classes, and four level II training classes. Each "training class" at any hierarchy level is taken as representative of the forest feature regarding spectral characteristics. Pairs of classes at all levels were classified one pair at one time, to obtain the pairwise correct classification accuracies (PCCA).

Figure 5 shows in bar-charts the PCCA versus feature pairs for level II, III, and the special level of general age classes displayed in sets of four bars: (1) best two channels of temporal data, (2) best two channels of November data, (3) best two channels of February data, and (4) best two channels of May data. The best channel sets were taken from results of section 4.3. Levels IV and V PCCA's are not presented in this paper but are available from Dillman and Kan (1975). PCCA between the softwood features of levels IV and V are generally between 50 and 60 percent, and those plots do not offer additional conclusions on the separability between those features. Plots of PCCA's for other channel set sizes are also available from Dillman and Kan (1975), and they show similar trends as in figure 5.

Level II PCCA's are high (from 87 to 99 percent) for all feature pairs at the best choice of data set (i.e., seasons or combinations of seasons) for channel set size of 2, except that softwood can only be separated from mixed softwood-hardwood with less than 80 percent. The lower PCCA between softwood and mixed softwood-hardwood is construed to be due to the definition of the two features (cf. section 2.2). Level III PCCA's are basically as high as level II PCCA's for softwood versus hardwood versus regeneration. Within the softwood and between softwood and mixed softwood-hardwood, PCCA's are as low as 61 percent.

The plot of figure 5(b) for the special level of general (softwood) age classes shows that separation between sawtimber and poletimber is poor (from 56 to 71 percent) where sawtimber versus regeneration or poletimber versus regeneration has PCCA above 95 percent. In other words, using LANDSAT-1 MSS sensor, the only significantly detectable age difference is between an established forest versus a young (or denuded) forest, i.e., regeneration.

The general trend of best season or combination of seasons is also discernible in figure 5; however, such conclusions are deferred to section 4.3, where additional divergence calculations and analysis are made.

4.3 Best Spectral Bands and Seasons

Using the training class statistics, the best channels from the temporal data set and the three individual season data sets were found for channel set sizes of 1, 2, 3, and 4. The prioritizing of channels was performed by ordering the magnitude of average divergence values between the training classes and was done for all levels of hierarchy. Table III tabulates that information.

From table III, it is apparent that the temporal data set (winter, early and late spring) offers the biggest overall average separability between all forest features at all hierarchy levels and at all channel set sizes (from 1 to 4 channels). The rating for individual seasons shows that February (phenological early spring) and May (phenological late spring) are better months than November (phenologically winter) for remotely sensing forest features in the Southeastern U.S. In particular, the red and near infrared channels of February and May data are good channels – channels 6 and 10 (sometimes 11 instead of 10) of the temporal data set.

Also, the average separability is shown to be lower at higher hierarchy levels, i.e., at higher details.

4.4 Classification Accuracy Versus Channel Set Size

Overall classification accuracies were also obtained when all classes were classified at the same time (in contrast with the pairwise cross-class classification described in section 4.2). Accuracies were obtained for all hierarchy levels, data sets, training fields, and a total of 24 test fields which were randomly distributed in the study site (Dillman and Kan, 1975). Only the test field overall classification accuracies are displayed in figure 6 versus the channel set sizes of 1, 2, 3, and 4 for the temporal and February data sets. Curves for May and November data sets are similar and lower than the February curves.

Increase in channel set size normally improves classification accuracy but it was found that the two best channels performed almost as well as three or four best channels. Thus the temporal data set proved superior to the other season data sets in classification accuracy and separability.

Apart from the above quantitative results, the entire study site was also classified and displayed in figure 7 for visual comparison with the unclassified MSS imagery of figure 3. The classification was performed on the temporal data set, using the best four channels (6, 8, 10, and 11) with the four level II forest features.

5.0 CONCLUSION

This computer-aided study has investigated quantitatively the spectral separability of timber types in Sam Houston National Forest of Texas, which is a typical forest in Southeastern United States, using LANDSAT-1 multispectral scanner data. Five hierarchy levels of mapping detail plus one level of general (softwood) age class were studied of three sets of data at winter, early and late spring. Also the temporal composite of those three data sets was studied. Seven conclusions are summarized as follows:

- The LANDSAT multispectral scanner sensor could be effectively used to separate the forest features of softwood, hardwood, and regeneration. Pairwise correct classification of training sets ranges from 87 to 99 percent and average correct classification for test fields ranges from 70 to 79 percent.

- The only significantly detectable age difference was between an established forest versus a young (or denuded) forest, i.e., regeneration. This conclusion was drawn from experience on softwood forests.

- The red (band 2: 0.6-0.7 micron) and one near infrared channel (band 3: 0.7-0.8 micron or band 4: 0.8-1.1 microns) of any of the three seasons (winter, early and late spring) would be better for discrimination.

- Phenological early and late spring could be equally good seasons for discrimination and would be better than the winter season. (Summer and autumn data were not available for analysis.)

- A temporal analysis using early and late spring LANDSAT data could improve classification accuracy up to 11 percent over single-season analysis.

- Analysis using the two best channels would perform almost as well as the four best channels for single-season or temporal analysis; hence, a two-channel analysis could be more cost-effective.

- It would be difficult to discriminate the forest features of mixed softwood-hardwood from the softwood feature by virtue of the definition of the two features: (1) softwood stand contains more than 50 percent softwood and (2) a mixed softwood-hardwood stand contains between 25 and 50 percent softwood.

It is observed that the capability of LANDSAT-1 is limited by many factors, including altitude, sensor design, and spatial data resolution. The last factor, in particular, will influence the level of mapping detail. A comprehensive study on forest classification and modeling has been reported by Kan et al. (1975).

REFERENCES

1. Aldrich, R. C., 1971: *Space Photos for Land Use and Forestry.* Photogrammetric Engineering, Vol. 37(3), pp. 389-401.

2. Anderson, T. W., 1958: *An Introduction to Multivariate Statistical Analysis.* John Wiley & Sons, New York, N.Y.

3. Anderson, J. R.; E. E. Hardy; and J. T. Roach, 1972: *A Land-Use Classification System for Use with Remote Sensor Data.* Geological Circular 671, Washington, D.C.

4. Anon., 1973: *Earth Resources Interactive Processing System, a Users' Manual.* International Business Machines Corp., Houston, Texas. Contract NAS9-966, NASA Johnson Space Center.

5. Anon., 1974: *Forestry Applications Exploratory Studies Project, a Preliminary Plan.* NASA Lyndon B. Johnson Space Center, Houston, Texas, Tech. Rep. JSC-09420, September 1974.

6. Chang, C. Y., 1971: *Divergence and Probability of Misclassification.* Lockheed Electronics Company, Inc., Houston, Texas, Tech. Rep. 640-TR-031, EOD 1750, September 30, 1971.

7. Colwell, R. N., 1973: *An Integrated Study of Earth Resources in the State of California Based on ERTS-1 and Supporting Aircraft Data.* Forestry Remote Sensing Laboratory, University of California, Berkely, California. NASA Contract NAS5-21827, Final Report, July 1973.

8. Dillman, R. D. and E. P. Kan, 1975: *Timber Type Separability Study of the Forestry Applications Project on Timber Resources.* Lockheed Electronics Company, Inc., Houston, Texas, Tech. Rep. LEC-____, August 1975.

9. Ells, T.; L. D. Miller; and J. A. Smith, 1972: *Users' Manual for RECOG (Pattern Recognition Programs).* College of Forestry and Natural Resources, Department of Watershed Science, Colorado State University, Fort Collins, Colorado, Science Series No. 3B, February 1972.

10. Erb, R. B.: *A Compendium of Analysis Results of the Utility of ERTS-1 Data for Land Resources Management.* National Aeronautics and Space Administration, the ERTS-1 Investigation (ER-600), Special Publication NASA SP-347, Johnson Space Center, JSC-08445, June 1974.

11. Ford-Robertson, F. C., 1971: *Terminology of Forest Science, Technology, Practice and Products.* Society of American Foresters, Washington, D.C.

12. Heller, R. C. et al.: *Evaluation of ERTS-1 Data for Inventory of Forest and Rangeland and Detection of Forest Stress.* Pacific Southwest and Rocky Mountains Forest and Range Experimental Stations, Final Report, Contract S-70251-AG, Sponsored by NASA Goddard Space Flight Center, Code 430 GSFC, Greenbelt, Maryland, December 1974.

13. Kan, E. P.; D. B. Ball; J. P. Basu; and R. L. Smelser, 1975: *Data Resolution Versus Forestry Classification and Modeling.* Proceedings of the second symposium on Machine Processing of Remotely Sensed Data held at Purdue University, W. Lafayette, Indiana, June 3-5, 1975.

14. Marill, T. and D. M. Green, 1963: *On the Effectiveness of Receptors in Recognition Systems.* IEEE Transactions on Information Theory, Vol. IT-9, January 1963.

15. Phillips, T. L. (editor), 1973: *LARSYS Version 3, Users' Manual.* Laboratory for Applications of Remote Sensing, Purdue University, W. Lafayette, Indiana, June 1973.

16. Society of American Foresters, 1954: *Forest Cover Types of North America.* Washington, D.C.

17. Sternitzke, H. S., 1967: *East Texas Piney Woods.* Southern Forest Experimental Station, Forest Service, U.S. Department of Agriculture, New Orleans, Louisiana.

18. Swain, P. H., 1973: *A Result from Studies of Transformed Divergence.* Laboratory for Applications of Remote Sensing, Purdue University, W. Lafayette, Indiana, Tech. Memo. 050173, May 1973.

19. Weber, F. P.; R. C. Aldrich; F. G. Sadowski; and F. J. Thomson, 1972: *Land Use Classification in the Southeastern Forest Region by Multispectral Scanner and Computerized Mapping in Monitoring Forest Land from High Altitude and from Space.* Pacific Southwest Forest and Range Experiment Station, Forest Service, USDA, Berkley, California.

TABLE I

NASA S 75 10965

FOREST HIERARCHY USED FOR CLASSIFICATION OF CONROE UNIT OF SAM HOUSTON FOREST

LEVEL I	LEVEL II	LEVEL III	LEVEL IV	LEVEL V	GENERAL AGE CLASSES	
FOREST LAND	SOFTWOOD	LOBLOLLY PINE	SAWTIMBER	MATURE, IMMATURE	SOFTWOOD	SAWTIMBER
			POLETIMBER	IMMATURE		
		SHORTLEAF PINE	SAWTIMBER	MATURE, IMMATURE		POLETIMBER
			POLETIMBER	IMMATURE		REGENERA-TION
	MIXED (SOFTWOOD, HARDWOOD)	LOBLOLLY/OAK/GUM	SAWTIMBER	IMMATURE		
	HARDWOOD	OAK, GUM	SAWTIMBER	IMMATURE		
	REGENERA-TION	—	—	SEEDLING/SAPLING, NON-STOCKED		

TABLE II

NASA S 75 10966

SPECTRAL CHANNEL COVERAGE OF TEMPORAL DATA FOR ANALYSIS OF THE CONROE UNIT OF SAM HOUSTON NATIONAL FOREST

TEMPORAL CHANNEL * NUMBER	DATE	LANDSAT BAND	WAVELENGTH (MICRON)
1	NOVEMBER	1	.5 TO .6
2		2	.6 TO .7
3		3	.7 TO .8
4		4	.8 TO .1.1
5	FEBRUARY	1	.5 TO .6
6		2	.6 TO .7
7		3	.7 TO .8
8		4	.8 TO .1.1
9	MAY	1	.5 TO .6
10		2	.6 TO .7
11		3	.7 TO .8
12 **		4	.8 TO .1.1

* NOMENCLATURE USED THROUGH OUT THIS PAPER

** NOT USED FOR ANALYSIS DUE TO EXCESSIVE NOISE

TABLE III

OPTIMUM CHANNELS AND CORRESPONDING AVERAGE PAIRWISE DIVERGENCE FOR FIVE LEVELS OF CLASSIFICATION: SAM HOUSTON NATIONAL FOREST

DATA SET	CHANNEL SET SIZE	LEVEL II		LEVEL III		LEVEL IV		LEVEL V		GENERAL AGE CLASSES	
		CHANNELS	AVERAGE DIVERGENCE	CHANNELS	AVERAGE DIVERGENCE	CHANNELS	AVERAGE DIVERGENCE	CHANNELS	AVERAGE DIVERGENCE	CHANNELS	AVERAGE DIVERGENCE
TEMPORAL DATA 11 CHANNEL*	4	6, 8, 10, 11	930	6 9 10 11	779	6, 8, 10, 11	769	3, 6, 8, 11	754	6, 8 10, 11	840
	3	6, 8, 10	897	6 10 11	740	6 8 11	728	6, 8, 11	704	6, 10, 11	799
	2	6, 10,	842	6 10	682	6 11	675	6,11	653	6, 10	754
	1	6	699	6	613	6	589	6	566	6	674
NOVEMBER	4	1, 2, 3, 4	666	1 2 3 4	570	1 2 3 4	610	1, 2, 3, 4	616	1 2 3 4	630
	3	1, 2, 4	658	1 2 4	556	1 2 4	575	1 2 3	574	1 2 4	615
	2	2 4	629	2 4	520	1 2	524	1 2	528	1 2	574
	1	2	586	2	476	2	481	2	498	2	516
FEBRUARY	4	5, 6, 7, 8	810	5 6 7 8	714	5 6 7 8	692	5, 6, 7, 8	667	5, 6, 7, 8	758
	3	5 6 8	798	5 6 8	704	5 6 8	673	5, 6, 8	649	5, 6, 8	750
	2	6 8	775	6, 8	676	6 8	638	6, 8	617	6, 8	727
	1	6	699	6	613	6	589	6	566	6	674
MAY	*4										
	3	9, 10, 11	808	9, 10, 11	671	9, 10, 11	674	9, 10, 11	663	9, 10, 11	707
	2	10, 11	800	10, 11	649	10, 11	638	10, 11	631	10, 11	699
	1	10	539	11	487	11	519	11	502	11	484

* CHANNEL 12 NOT USED DUE TO EXCESSIVE NOISE, HENCE NO CHANNEL ORDERING FOR MAY DATA AT SET SIZE OF 4.

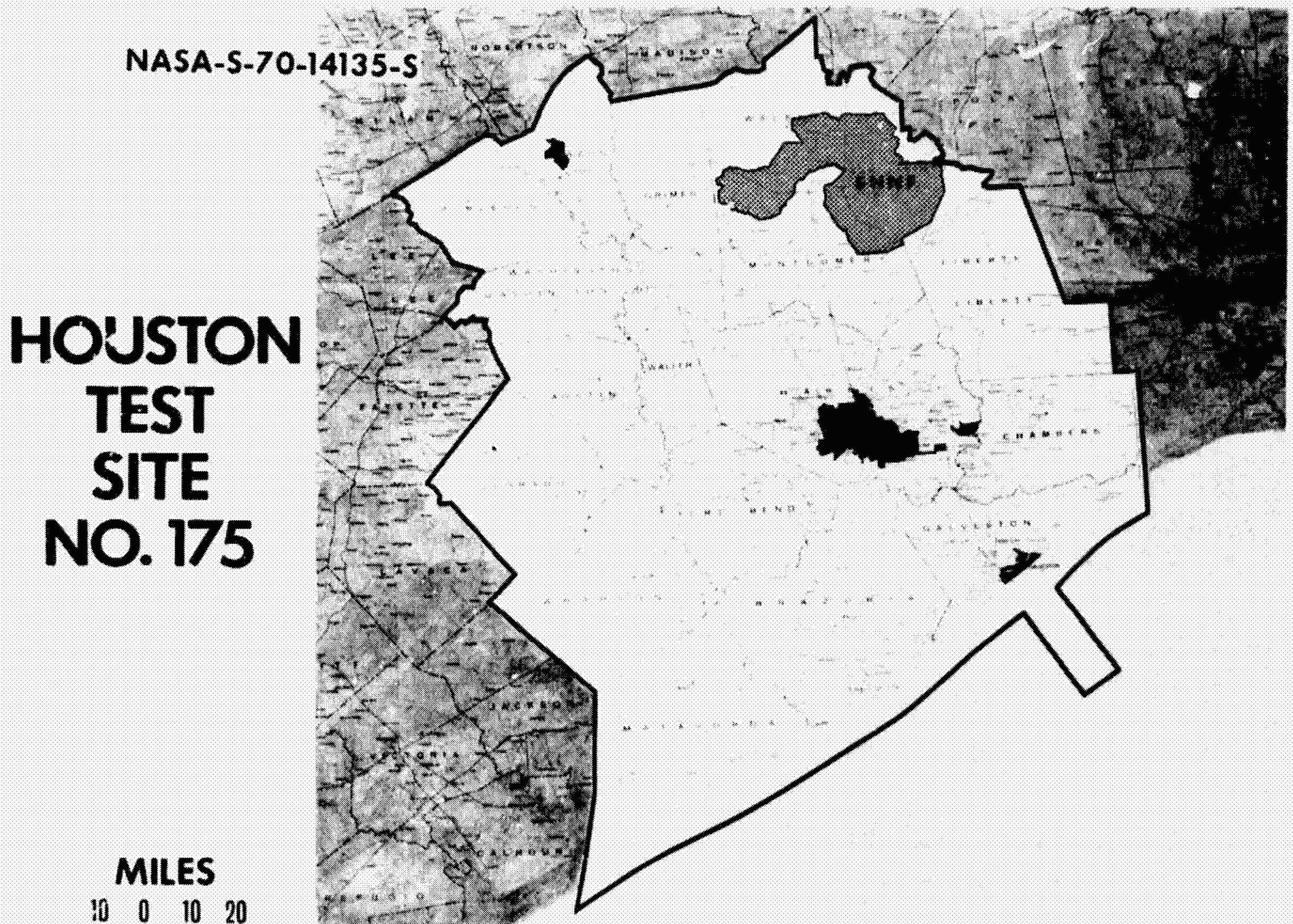


Figure 1. — Location of Sam Houston National Forest (shaded area).

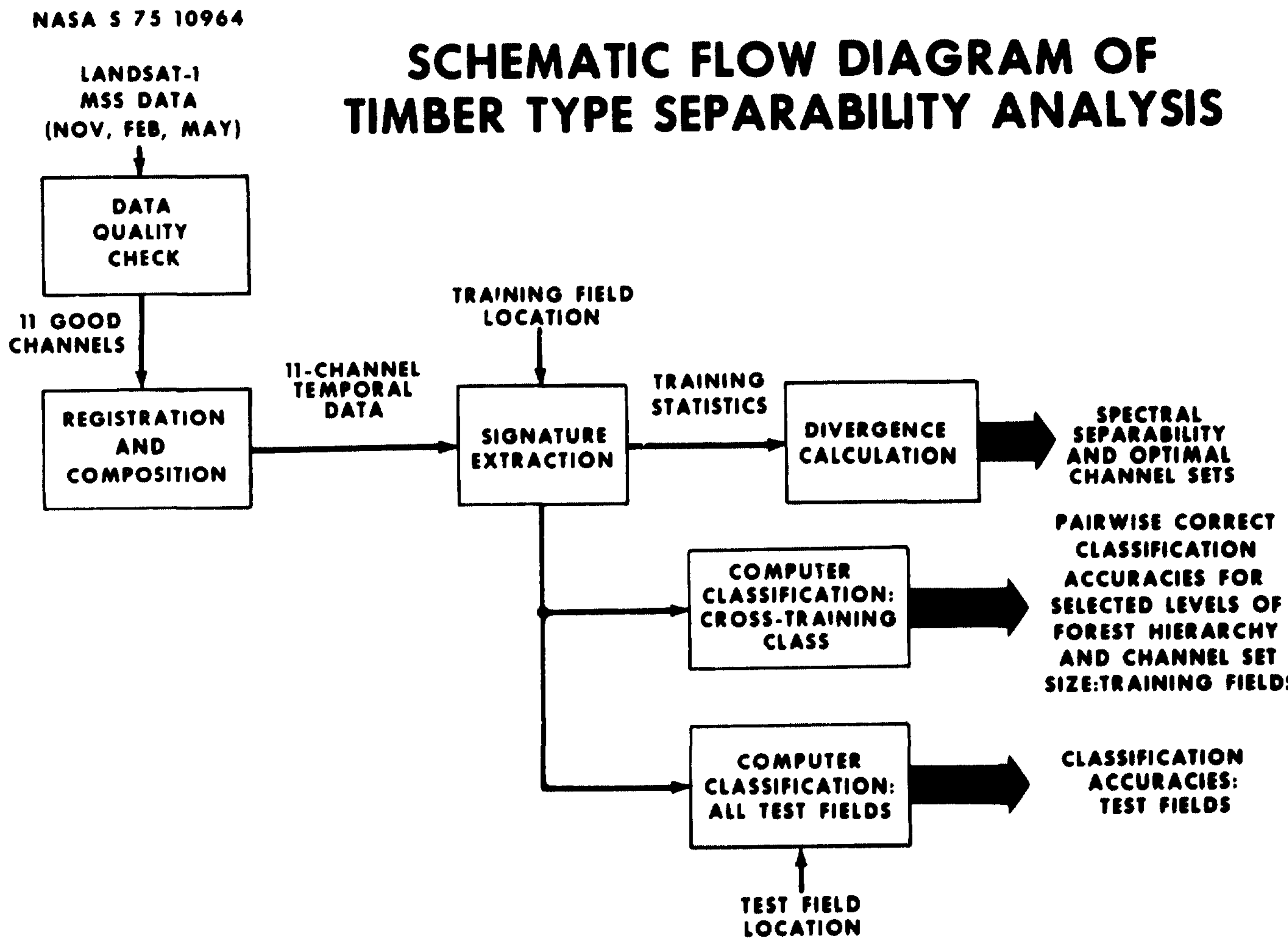

NASA S 75 10964
SCHEMATIC FLOW DIAGRAM OF
TIMBER TYPE SEPARABILITY ANALYSIS
LANDSAT-1
MSS DATA
(NOV, FEB, MAY)
DATA
QUALITY
CHECK
11 GOOD
CHANNELS
REGISTRATION
AND
COMPOSITION
11-CHANNEL
TEMPORAL
DATA
TRAINING FIELD
LOCATION
SIGNATURE
EXTRACTION
TRAINING
STATISTICS
DIVERGENCE
CALCULATION
SPECTRAL
SEPARABILITY
AND OPTIMAL
CHANNEL SETS
COMPUTER
CLASSIFICATION:
CROSS-TRAINING
CLASS
PAIRWISE CORRECT
CLASSIFICATION
ACCURACIES FOR
SELECTED LEVELS OF
FOREST HIERARCHY
AND CHANNEL SET
SIZE:TRAINING FIELDS
COMPUTER
CLASSIFICATION:
ALL TEST FIELDS
CLASSIFICATION
ACCURACIES:
TEST FIELDS
TEST FIELD
LOCATION

Figure 2

NASA S 75 10961

RAVEN DISTRICT OF SAM HOUSTON NATIONAL FOREST, LANDSAT - 1 IMAGE BAND 2, .6 - .7 μm, FEBRUARY 25, 1973 (CONROE UNIT, STUDY SITE OUTLINED)

Figure 3

NASA S 75 10968

LANDSAT, SPECTRAL SIGNATURE MEAN PLOT FOR LEVEL V TRAINING FIELDS

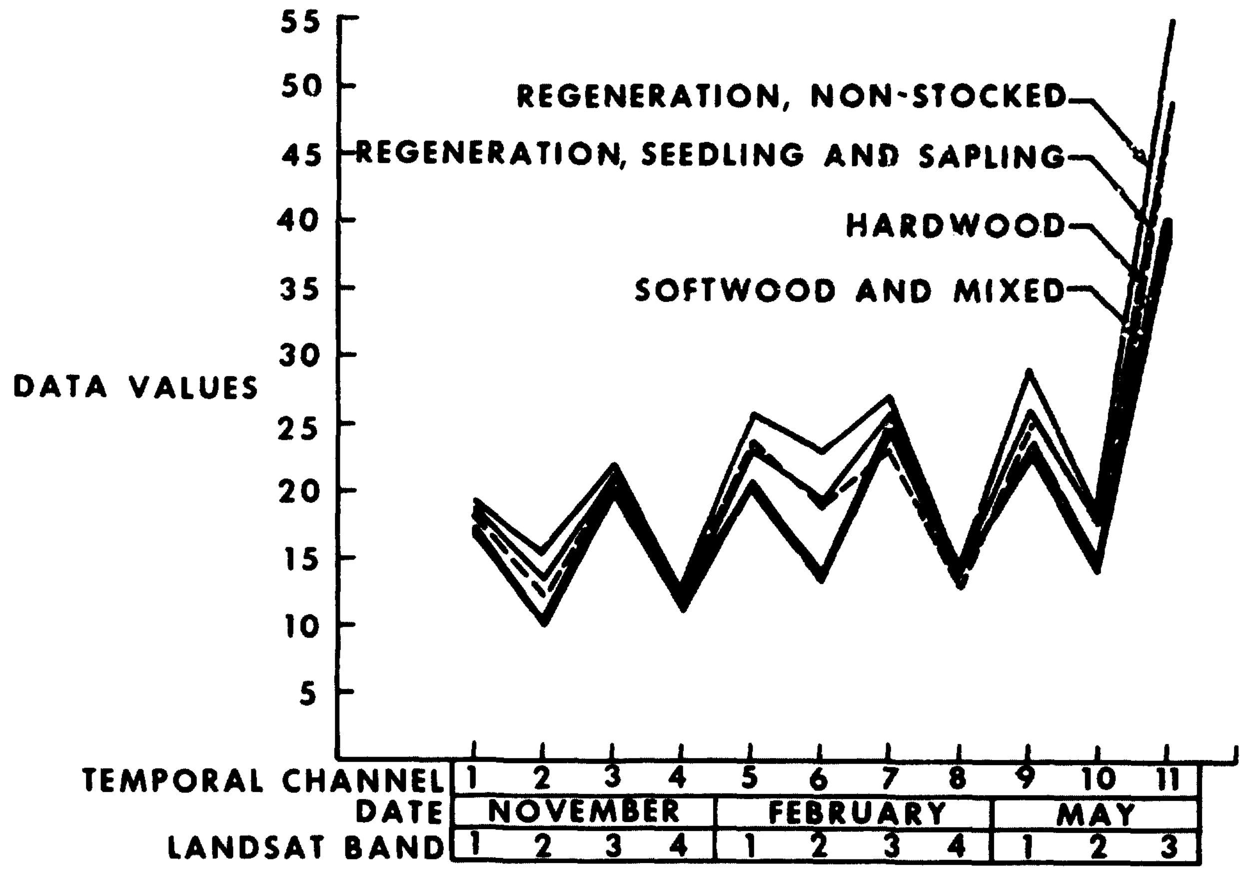


Figure 4

NASA S 75 10970

AVERAGE PAIRWISE CORRECT CLASSIFICATION ACCURACIES OF SAM HOUSTON NATIONAL FOREST TRAINING FIELDS FOR THREE LEVELS OF HIERARCHY, USING BEST 2 CHANNELS FOR 4 DATA SETS: (a) LEVEL II

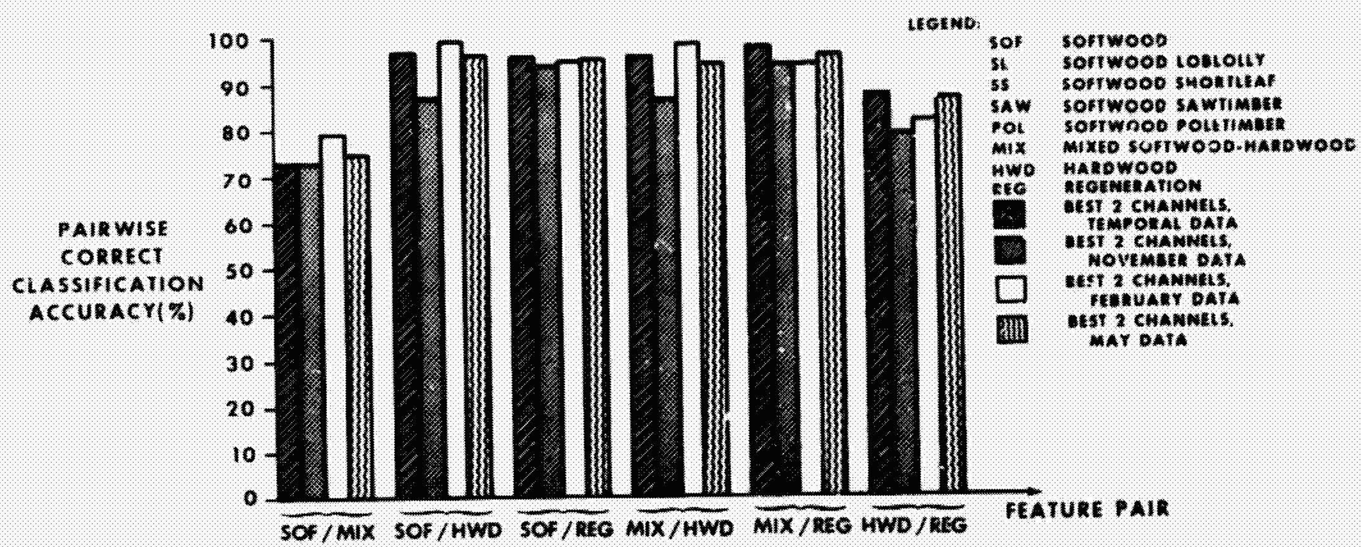


Figure 5(a)

NASA S 75 10971

AVERAGE PAIRWISE CORRECT CLASSIFICATION ACCURACIES OF SAM HOUSTON NATIONAL FOREST TRAINING FIELDS FOR THREE LEVELS OF HIERARCHY, USING BEST 2 CHANNELS FOR 4 DATA SETS: (b) LEVEL OF GENERAL AGE CLASSES

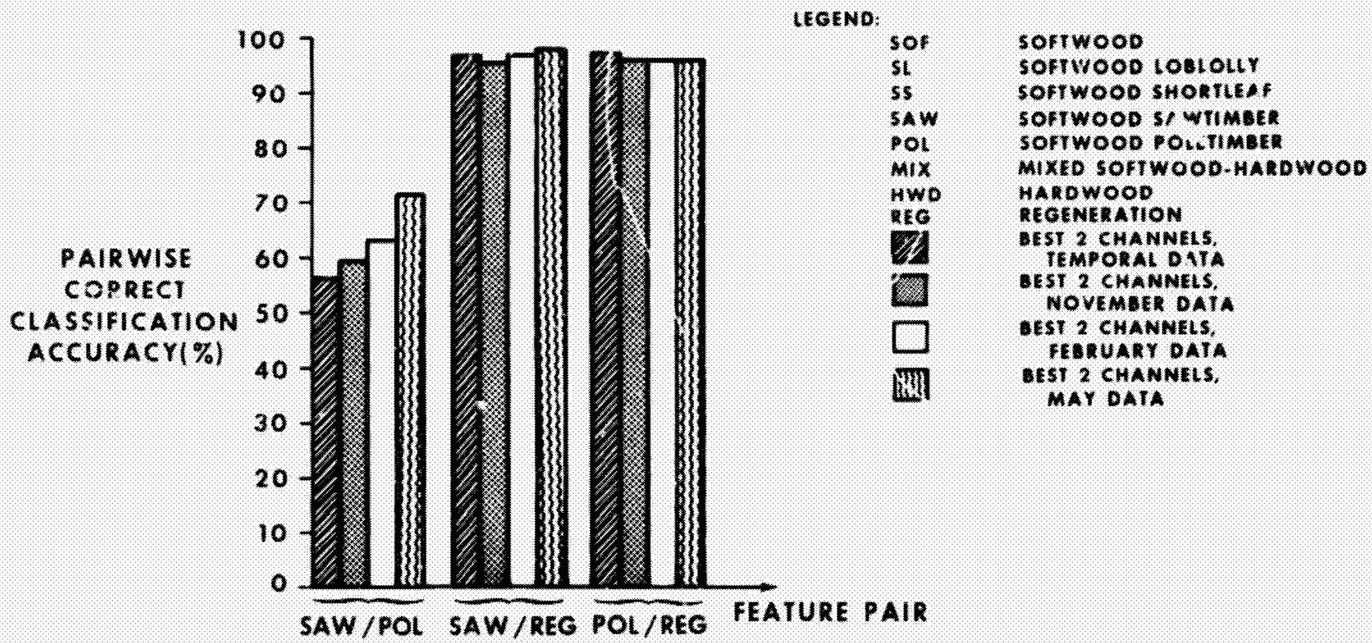


Figure 5(b)

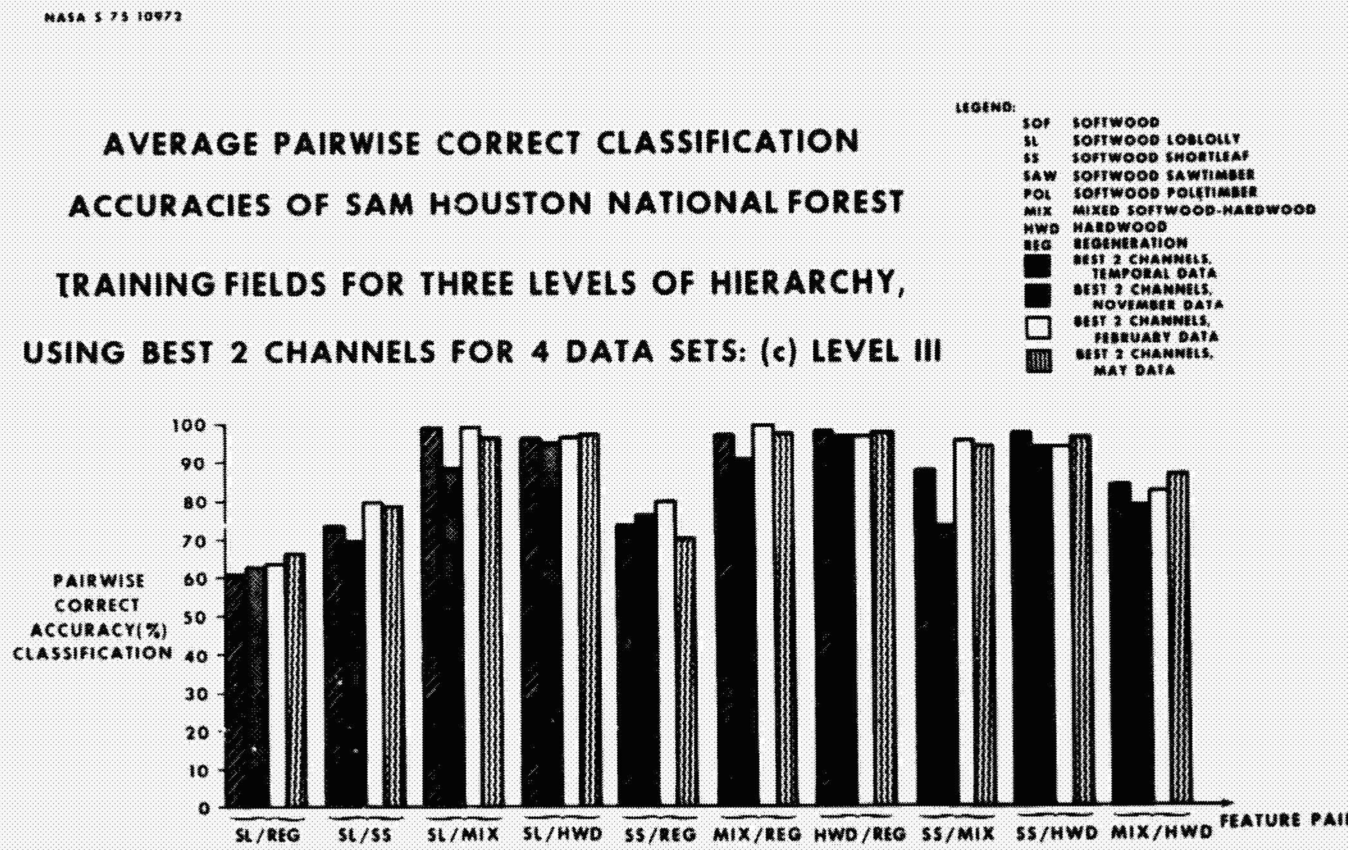

NASA S 75 10972
AVERAGE PAIRWISE CORRECT CLASSIFICATION
ACCURACIES OF SAM HOUSTON NATIONAL FOREST
TRAINING FIELDS FOR THREE LEVELS OF HIERARCHY,
USING BEST 2 CHANNELS FOR 4 DATA SETS: (c) LEVEL III
LEGEND:
SOF SOFTWOOD
SL SOFTWOOD LOBLOLLY
SS SOFTWOOD SHORTLEAF
SAW SOFTWOOD SAWTIMBER
POL SOFTWOOD POLETIMBER
MIX MIXED SOFTWOOD-HARDWOOD
HWD HARDWOOD
REG REGENERATION
BEST 2 CHANNELS, TEMPORAL DATA
BEST 2 CHANNELS, NOVEMBER DATA
BEST 2 CHANNELS, FEBRUARY DATA
BEST 2 CHANNELS, MAY DATA
PAIRWISE CORRECT ACCURACY(%) CLASSIFICATION
100
90
80
70
60
50
40
30
20
10
0
SL/REG
SL/SS
SL/MIX
SL/HWD
SS/REG
MIX/REG
HWD/REG
SS/MIX
SS/HWD
MIX/HWD
FEATURE PAIR

Figure 5(c)

NASA S 75 10969

AVERAGE CORRECT CLASSIFICATION ACCURACIES FOR SAM HOUSTON NATIONAL FOREST TEST FIELDS USING LANDSAT CHANNEL SETS OF SIZE 4, 3, 2, 1 FOR SELECTED LEVELS OF HIERARCHY AND DATES

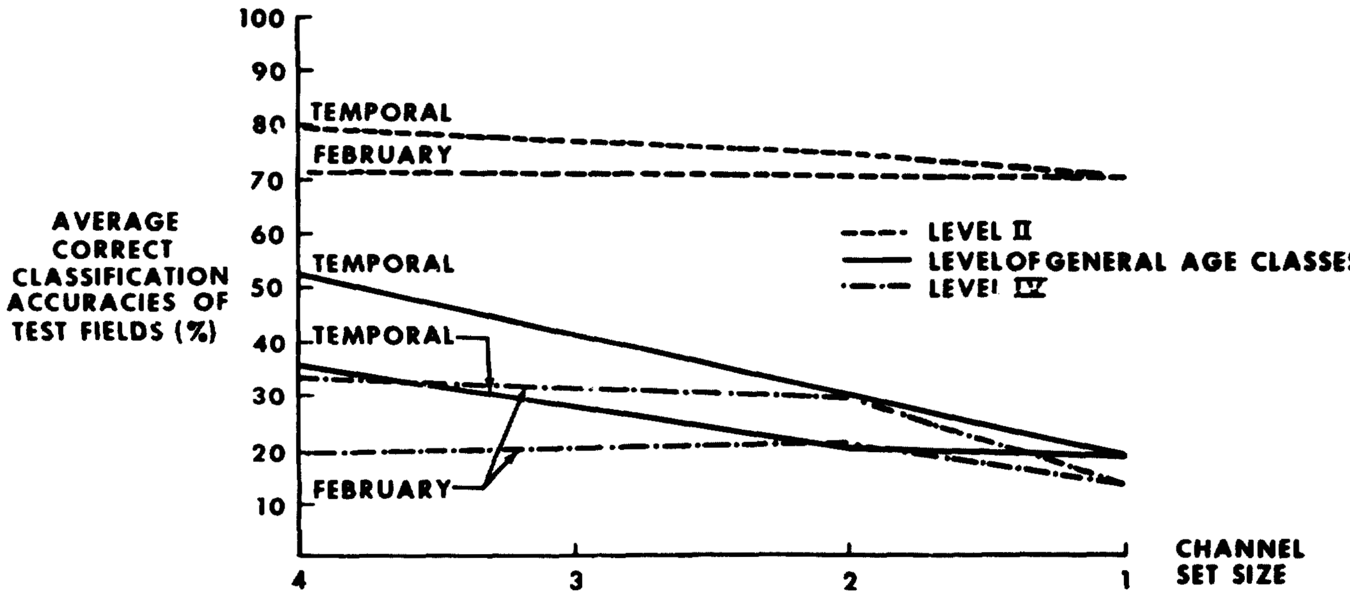


Figure 6

NASA S 75 10962

LEVEL II CLASSIFICATION OF CONROE STUDY SITE USING FOUR CHANNELS 6, 8, 10, 11 TEMPORAL DATA

	WHITE	SOFTWOOD
GRAY	LIGHT	REGENERATION
	MED	MIXED SOFTWOOD/ HARDWOOD
	DARK	HARDWOOD
	BLACK	UNCLASSIFIED

N ↑

Figure 7

A-12

MAPPING OF THE WILDLAND FUEL CHARACTERISTICS OF THE SANTA MONICA MOUNTAINS OF SOUTHERN CALIFORNIA

By J. D. Nichols,* University oi California, Berkeley, California

ABSTRACT

LANDSAT digital MSS data was successfully used to map and evaluate the wildland fuels of the Santa Monica Mountains in Southern California. A mixed classification scheme was used where training areas of known vegetation types were entered and the maximum likelihood classifier run, followed by an evaluation of the results and an unsupervised retraining of the classifier using an image of the probability of misclassification.

Estimation of maturity class and crown closure percents of the major cover types were assigned to each computer class by associating the photo interpretation of 159 large scale photo samples with the resultant computer classes using analysis of variance and analysis of categorized data. The result of the computer classification and statistical analysis were then transformed from the LANDSAT Coordinate California State Plane Coordinate system for use in a digital format in the FIRESCOPE data retrieval and fire modeling system.

OBJECTIVE

The primary objective of this FIRESCOPE funded study was to determine the potential of LANDSAT digital multispectral scanner data for meeting the requirements for identification and mapping of surface characteristics necessary for forest fire management in the Santa Monica mountain areas in Southern California. This required a determination of the adequacy of the spectral, spatial and multi-date capabilities of the LANDSAT MSS scanner, and the investigation of an integrated LANDSAT, photographic and ground data collection system for use in the operational mapping of wildland fuels. The major factor to be determined in the study was the usefulness of LANDSAT-derived data as an input to the information system being developed under project FIRESCOPE.[1] A secondary objective was to devise an operational procedure for the mapping of wildland fuels.

APPROACH

Supervised computer classification of LANDSAT digital multispectral scanner data was done using initial training from 28 areas selected from LANDSAT photographic products, high flight photography and large scale photography (See Table I). Retraining of areas with a low probability of correct classification was accomplished through use of the classification results and an image of a histogram of the probability of correct classification. The results were verified by precisely locating large scale photographs in the LANDSAT classification results and comparing LANDSAT

---

* Former Director of the Remote Sensing Research Program; currently Head of Earth Resources Technology Applications, Electromagnetic Systems Labs., ESL Incorporated, Sunnyvale, CA.

1 FIRESCOPE: An interagency program to apply advanced technology to the wildfire suppression problem in Southern California. The study was funded and administered by the USFS's Pacific Southwest Forest and Range Experiment, Riverside Fire Laboratory.

classes with the vegetation fuel types identified on the large scale photos. The LANDSAT results were then mapped to the fire model coordinate system through the use of common control points in the LANDSAT imagery and in the ground coordinate system. The transformation was obtained using least square estimation procedures.

TABLE I.

	Class Name	Symbol	Description
1.	URNE	.	Urban
2.	URN	,	Urban
3.	BR. -4	-	Predominantly immature brush with patches of mature brush
4.	GRB1	/	Barren land with some grass associated with urban development
5.	GRB2	(	Barren land associated with new housing
6.	BR-SWS	]	Predominantly mature brush, patches of immature brush, found on Southwest slopes
7.	BR-5	=	Immature brush with grass understory - 50% crown closure of brush
8.	GRC	≠	Barren land associated with new housing, very sparse grass cover
9.	BR-NE	≡	Mature brush found on northeastern slopes
10.	OPEN2A	I	Grass with riparian vegetation (willow)
11.		0	Open grassland
12.	BR-1-25	8	Mature brush mixed with live oak of 30-50% crown cover
13.	OPEN-1	×	Oak grassland with 40-60% crown closure of oak
14.	OPEN-3	W	Oak grassland with 20-40% crown closure of oak
15.	OPEN-4	4	Grassland
16.	BR-1-19	?	Mature brush mixed with live oak; average 50% crown closure
17.	UR-5	→	Training from developed area but class is basically mature brush similar to class #16
18.	BURNER	v	Immature brush with some mature patches - grass understory present
19.	B.S. -1	↑	Barren area - no grass
20.	URN 2A	<	Developed area with no vegetation
21.	URN2B	≥	Developed area with no vegetation
22.	URD1B	¬	Developed area with no vegetation
23.	BR. -1	;	Mature brush with sparse live oak
24.	URD	H	Urban development

TABLE I. -- Continued.

	Class Name	Symbol	Description
25.	OCEAN	J	Water - fresh and ocean
26.	UR-B	G	Urban
27.	SAND	9	Beach sand
28.	NEWHO	7	New Housing (Barren land)
29.	OPEN6	A	Oak grassland
30.	OPEN7	B	Oak grassland

The final classes selected for the supervised classification are shown here. The columns represent the computer class number, class name, class symbol and a general class description. The description is a result of the correlation of interpretation of large scale photos (1:1000 color) and high flight photo (1:30,000 color infrared) with discriminant analysis classes.

PROCESSING STEPS USED IN THE DISCRIMINANT ANALYSIS AND MAPPING OF WILDLAND FUELS IN THE SANTA MONICA MOUNTAINS

The following individual steps were used in the extraction, discriminant analysis, verification and mapping of the wildland fuels of the Santa Monica Mountains.

1. The LANDSAT multispectral scanner computer compatible tapes were reformatted to make them compatible with the local automatic data processing system.
2. The area of interest was then extracted from the reformatted tapes and placed on a separate tape to reduce the cost of further processing.
3. Due to the improper calibration between the individual sensors in each of the four bands, the tapes were recalibrated to minimize errors from this source.
4. Large scale stereo pairs were acquired at approximately 1/8 mile intervals over 11 flight lines distributed throughout the Santa Monica Mountains. The photos were at an average scale of 1:1000 with simultaneous medium scale photos acquired to aid in the interpretation and location of the large scale photo pairs.
5. The large scale and medium scale photos were annotated, mounted, and interpreted to determine crown cover, species composition, and general vegetation condition.
6. Through use of the large and medium scale photos, the X, Y, coordinates of each training area were located in the LANDSAT computer compatible tapes.
7. Points that could be easily located in the LANDSAT computer compatible tapes were also identified and located on 7-1/2 minute quadrangles. The tape X, Y, coordinates and the corresponding map UTM coordinates of these control points were then determined.
8. Least squares estimation procedures were used to determine the coefficients of the transformation equations necessary to map the LANDSAT data to the UTM coordinates to LANDSAT data. This data base was also used to determine the LANDSAT-to-LANDSAT

multidate transformation for four dates. (This was part of another study to investigate the geometric fidelity of the LANDSAT data for multidate ov- -.y.)

9. A LANDSAT-to-LANDSAT multidate tape was made and training areas extracted to determine the value of multidate imagery in the fuel mapping process.

10. From the four dates available for computer processing, the optimum date was selected. This selection was based on the uniformity of illumination, vegetation condition, atmospheric conditions, and quality of the digital tape data.

11. The raw data obtained from the training areas were processed in the statistical subroutine of the discriminant analysis package to determine the uniqueness of the various classes and to allocate further training of the classifier as needed.

12. The UTM coordinates of each of the large scale photo plots were obtained by first locating the plots on 7-1/2 minute quadrangles and then measuring their UTM coordinates. The LANDSAT coordinates of each of these photo plots were then computed using the UTM-to-LANDSAT transform.

13. The existing fuel classification, as completed by manual photo interpretation, was compared with the interpretation of the large scale photographs to determine the relationship between the two fuel classification procedures.

14. The "maximum likelihood" classifier was run repeatedly until an adequate separation of the various vegetation types was obtained. The discriminant analysis results and probability map were used in combination to locate areas where new training was needed and determine the exact X, Y, coordinates of these new training areas.

15. The discriminant analysis results were then run through the reclassification program. In this step each picture element was reclassified to the class that occupied the most points in the eight points surrounding the picture element being reclassified plus the central picture element. This procedure produced a map similar to the map produced by a photo interpreter when the interpreter is restricted to a 10-acre mapping minimum.

16. The LANDSAT coordinates of the photo plots were used to obtain the raw LANDSAT classification and the reclassification results of each of the photo plots. The relationship between the LANDSAT classification results and the photo interpreted results for the large number of large scale photos was then determined.

17. A summary was made of the acreages of the various fuel classes.

18. A dot count method was then used to determine the percentage of trees, brush, grass and barren area on the photo plots that had been precisely located in the LANDSAT discriminant analysis process. Each of the plots was als assigned one of the maturity classes, viz: barren, pioneer, immature or mature.

19. Four one-way analyses of variance runs were made to determine whether the discriminant analysis results explained the differences in tree cover, brush cover, grassy areas and bare soils. The procedure also ranked each of the discriminant analysis classes by the percent trees, brush, grass and bare soil (See Table II).

20. Several high resolution color coded maps were then made using the optical mechanical image reproducer. The colors represented such factors as maturity, density, and cover type.

The major product of this study is a discriminant analysis of vegetation for the Santa Monica Mountains. From this basic product a transformed image is produced that fits the ground coordina- sys- em used in the fire modeling. A hard copy map product will be generated from the transform results and summary statistics thereby providing information on acreage by fuel type.

TABLE II

CLASS NUMBER	% TREES	% BRUSH	% GRASS	% BARE SOIL
12	86.9	9.5	2.2	1.4
23	67.2	24.7	8.5	1.0
9	55.9	35.1	5.7	2.1
16	55.9	34.4	6.3	3.2
17	52.3	47.6	0.0	0.0
6	47.8	40.0	8.9	3.2
13	41.2	21.0	28.9	7.9
30	30.0	11.9	18.2	5.0
3	29.9	37.4	24.3	9.5
18	24.1	45.0	21.4	8.7
14	21.0	20.1	56.3	2.0
15	19.3	28.5	42.6	10.6
7	17.0	50.4	27.0	5.6
AVERAGE PERCENTAGE COVER	45.3	34.7	15.3	4.8

This table gives the percent composition of trees, brush, grass and bare soil for each of the discriminant analysis classes for which photo plots were obtained. The estimates of the percentage cover are based on a least squares procedure. Each of the large scale photo plots was assigned to the computer class for that ground location. The average percent cover for each computer class was then computed for each of the four cover types.

EVALUATION OF CLASSIFICATION ACCURACY

Three major comparisons were made in evaluating results of discriminant analysis and comparing those results with the results of existing vegetation mapping for fuel type. First, the percentage correct classification within each of the training fields was computed as a normal product of the classifier (See Table III). The percentage correct by common subclasses also was computed for the mature brush, immature brush, pioneer, grassland and urban categories. The percentage correct as determined within these training fields only, did not provide a rigorous evaluation of the classifier for the entire study area. Therefore, the large scale flight lines were flown and the photo plots precisely located in the discriminant analysis results. The computer classification results, as applied to each of the p[illegible] separated the photo plots according to the classification results and provided an independent check of the classification accuracy and consistency for the entire study area.

TABLE III. SUMMARY OF STATISTICS OBTAINED IN CLASSIFYING LANDSAT DATA.

Class No.	Class Name	Class Symbol	Mean for Training Area: 500-600nm Ch 1	Mean for Training Area: 600-700nm Ch 2	Mean for Training Area: 700-800nm Ch 3	Mean for Training Area: 800-1100nm Ch 4	Percent Correct Within Training Area: Class	Percent Correct Within Training Area: Recl.	Classification: No. of Pixels	Classification: % of Total	Classification: Acres
1	URNE	.	40.37	39.47	48.21	23.16	95	100	4407	2.39	4803.6
2	URN	,	39.24	35.88	43.40	20.36	68	100	11242	6.09	12253.8
3	BR.-4	-	36.17	35.17	39.50	18.17	100	100	14470	7.84	15772.3
4	GRB1	/	47.83	52.67	49.67	20.67	100	67	384	0.21	418.6
5	GRB2	(	47.33	55.50	56.17	25.67	100	67	1073	0.58	1169.6
6	BR-SWS	]	31.40	26.60	33.50	16.60	100	100	12067	6.83	13741.6
7	BR-5	=	32.00	28.87	30.12	14.87	88	88	5027	2.73	5479.4
8	GRC	≠	50.73	56.82	55.18	24.64	91	91	5013	2.72	5464.2
9	BR-NE	≡	30.16	25.16	36.32	19.16	68	95	25994	14.09	28333.5
10	OPEN2A	I	40.75	48.50	51.75	25.00	88	88	1816	0.98	1979.4
11	OPEN2B	0	37.40	43.90	46.40	22.60	70	90	4832	2.62	5266.9
12	BR-1-25	8	27.67	22.56	32.44	17.44	100	100	4988	2.70	5436.9
13	OPEN-1	×	37.78	39.78	44.22	21.67	56	56	5051	2.74	5505.6
14	OPEN-3	W	36.69	39.94	42.56	21.12	69	75	5822	3.16	6346.0
15	OPEN-4	4	40.14	46.02	47.71	23.21	48	81	14173	7.68	15448.6
16	BR-1-19	?	28.94	25.74	32.37	17.20	80	100	14892	8.07	16232.3
17	UR-5	→	29.25	24.50	31.25	16.25	100	75	1882	1.02	2051.4

TABLE III. -- Continued.

Class No.	Class Name	Class Symbol	Mean for Training Area				Percent Correct Within Training Area		Classification		
			500-600nm Ch 1	600-700nm Ch 2	700-800nm Ch 3	800-1100nm Ch 4	Class	Recl.	No. of Pixels	% of Total	Acres
18	BURNER	v	32.40	30.40	31.65	15.25	80	100	13572	7.36	14793.5
19	B.S.-1	↑	50.67	56.92	55.33	23.00	58	75	1232	0.67	1342.9
20	URN2A	<	69.67	68.00	67.83	31.00	100	100	512	0.28	558.1
21	URN2B	≥	58.75	54.75	58.50	26.00	100	25	138	0.07	150.4
22	URD1B	¬	83.50	85.37	82.50	35.00	100	100	235	0.13	256.1
23	BR.-1	;	28.34	42.06	28.48	14.28	72	92	11356	6.16	12378.0
24	URD	H	45.32	42.88	45.60	20.84	96	100	10658	5.78	11617.3
25	OCEAN	J	30.56	20.30	13.64	3.91	100	100	53533	--	58351.0
26	UR-8	G	44.87	41.88	37.87	15.75	100	100	1466	0.79	1597.9
27	SAND	9	57.09	59.91	52.73	21.09	100	100	356	0.19	388.0
28	NEWHO	7	51.85	57.42	53.75	22.42	75	75	1673	0.91	1823.6
29	OPEN6	A	38.50	42.00	45.08	21.92	83	91	2551	1.38	2780.6
30	OPEN7	B	37.73	40.53	43.20	21.27	20	20	7051	3.82	7685.6

COORDINATE TRANSFORMATION

Three basic coordinate transforms were needed to complete this study. First, to compare the statistics from the multidate aspects of LANDSAT, a LANDSAT-to-LANDSAT coordinate transform was necessary. Second, to locate photo plots in the LANDSAT tape data, UTM-to-LANDSAT transformation was necessary, and third, to map the LANDSAT coordinate system to a ground coordinate system, LANDSAT-to-UTM transformation was necessary. Additionally, a LANDSAT-to-California plane coordinate system transform was necessary to permit the data to be used in the fire model. In general, each coordinate transformation is in error by less than one picture element for all control points. When the large scale photo plots are located on the maps and then transformed to the LANDSAT coordinates and the results of the discriminant analysis classification observed, it becomes very apparent that the LANDSAT-to-UTM and UTM-to-LANDSAT transformations were very accurate over the entire scene. In all cases checked, the features immediately surrounding the photo centers can easily seen and the results of the classification verified through the use of a minimal amount of photo interpretation of the large and medium scale photos.

SUMMARY OF SIGNIFICANT RESULTS

1. It was anticipated that the computer would correctly classify 85% ± 10% of the picture elements within the computer training areas The observed percentage correct was 82.7%. When training areas that represented equivalent fuel types were pooled, the percentage correct rose to 95.0%.
2. Trees, brush, grass, and bare soil are adequately separated by discriminant analysis of the LANDSAT multispectral scanner data as evidenced by results obtained in attempting to determine the percentage cover of each.
3. The raw (initial) classification results are more accurate than the reclassification results.
4. The four maturity classes (barren, pioneer, immature and mature) are adequately separated by the discriminant analysis
5. When broad and environmentally based delineations are made, separating the area into relatively homogeneous types, the discriminant analysis procedure appears to adequately separate types by species composition.

The results of this study and other wildland studies indicate that the discriminant analysis of LANDSAT data provides a cost-effective base for sample allocation. This data base, when used to allocate large photo flight lines, which in turn are used to allocate ground samples, significantly increases the precision of resource estimates over that obtainable by conventional techniques. The integrated procedure reduces the cost of inplace mapping, inventory, and assessment from 2:1 to 20:1 depending on the complexity of the problem and the relative amount of information obtained from the LANDSAT discriminant analysis.

COMPUTER ANALYSIS AND MAPPING OF GYPSY MOTH DEFOLIATION LEVELS IN PENNSYLVANIA USING LANDSAT-1 DIGITAL DATA* A-13

By Darrel L. Williams, NASA/Goddard Space Flight Center, Greenbelt, Maryland

N76-17481

ABSTRACT

The purpose of this study was to investigate the effectiveness of using LANDSAT-1 multispectral digital data and imagery, supplemented by ground truth and aerial photography, as a new method of surveying gypsy moth (Porthetria dispar (L.)) (Lepidoptera; Lymantriidae) defoliation, which has greatly increased in Pennsylvania in recent years. Since the acreage and severity of gypsy moth defoliation reaches a peak from mid-June through the first few days of July, the July 8, 1973, LANDSAT-1 scene was chosen for analysis. Results indicate that LANDSAT-1 data can be used to discriminate between defoliated and healthy vegetation in Pennsylvania and that digital processing methods can be used to map the extent and degree of defoliation.

INTRODUCTION

Endemic populations of defoliating insects are common in forests, but seldom cause noticeable damage. Although there are many defoliating insects from various orders, insects of the order Lepidoptera generally account for most defoliations.[1, 2] If these insect populations explode, serious damage may result. For instance, heavy defoliatior affects stream flow, reduces wildlife habitat, increases fire and erosion hazards, increases the susceptibility of forest vegetation to other insects or disease, reduces tree growth, and increases tree mortality. In addition, defoliation, and the presence of the insects, create an aesthetically unattractive appearance at a time of the year when tourism is at its peak, resulting in significant reductions in the value of public and private recreational lands and financial loss to the tourist industries. Where heavy mortality on commercial forest land occurs, large-scale salvage operations seem to offer the best means of reducing financial loss. However, substantial losses are incurred, and plans for maintaining a continuous flow of timber products are disrupted, whenever immature stands are harvested.

One such insect, the gypsy moth (Porthetria dispar (L.)) (Lepidoptera: Lymantriidae), has increased and spread in epidemic proportions throughout much of the mixed woodlands of eastern and central Pennsylvania in recent years. The alarming rate of increase may best be expressed by noting that the defoliated acreage in Pennsylvania increased by 113 percent over that in 1972, for a total of about 348,000 hectares (860,000 acres) in 1973.[3] In the entire northeastern United States, the gypsy moth partially defoliated at least 688,000 hectares (1.7 million acres) of forest in 1973.[4] In 1974, approximately 162,000 hectares (400,000 acres) were defoliated in Pennsylvania. The noticeable reduction in defoliation was mainly due to population collapses in the northeastern counties, but the areal extent of defoliation in central Pennsylvania greatly increased.

Considerable research has been done in an attempt to eradicate the gypsy moth, but the task of eradication is an economic, if not physical, impossibility. Therefore, in recent years, there has been an increased emphasis directed toward the development of an effective suppression program. To initiate and sustain such a program, the agencies responsible for control must have early, accurate, and efficient methods of detection and mapping. In the past, many survey techniques have been applied to the problem of detection, including ground surveys, aerial surveys, and photographic or remote sensing surveys with subsequent photointerpretation and mapping.

The oldest technique, the ground survey, is used to obtain such information as the extent of defoliation, refoliation, and mortality. Its only advantage over the other types of surveys is that by

*Research project 2025 of the Pennsylvania Agricultural Experiment Station. Financial support furnished by McIntire-Stennis funds.

close observation on the ground one can quickly and accurately identify the tree species attacked. Major disadvantages include the great amount of time, and consequent cost, required to cover large areas, and the many changes which can occur in the forest canopy during the time required to carry out the survey.

One commonly used aerial survey method, known as sketch mapping, relies on the extensive use of light aircraft with an observer directly mapping the extent of defoliation onto topographic maps. This method has the potential of providing timely and accurate data related to areal extent of defoliation, but the precision of mapping is inherently affected by the observer's knowledge of the local geography and his ability to relate this to what he sees from the air. In addition, inaccuracies may occur due to fatigue and air discomfort, changes in the forest canopy during the time required to complete the survey over vast areas, and differences between observers' interpretations of the various defoliation categories.

Photographic surveys have been widely used in recent years for assessing forest defoliation or mortality. Croxton[5] reported successful detection and classification of ash dieback using color aerial photography. Wert and Roettgering[6] described the use of aerial color photography for inventorying mortality in Douglas-fir (Pseudotsuga taxifolia) resulting from attacks by the Douglas-fir beetle (Dendroctonus pseudotsugae Hopk.) (Coleoptera: Scolytidae), while Bousfield[7] used aerial photography to estimate the volume of timber losses in northern Idaho caused by the same insect. Rohde and Moore[8] tested the utility of large-scale aerial photography for detecting and evaluating gypsy moth defoliation, and results revealed that defoliation was easily detected. Furthermore, they stated that

> . . . remote sensing techniques, when properly used, can provide . . .: (1) timely data with respect to time of defoliation and subsequent refoliation and mortality, (2) synoptic data providing accurate delineation of areal extent of damage, (3) permanent records of forest composition and damage for more detailed studies at a later date to evaluate recovery rates, species composition, tree condition, tree size, stocking, density, number of trees killed, etc., and (4) direct management information with respect to planning effective suppression operations. (p. 13)

Many researchers have found remote sensing techniques to be considerably cheaper than previous survey methods. Wert and Wickman[9] reported that the use of color photography for obtaining estimates of mortality caused by the Douglas-fir tussock moth (Hemerocampa pseudotsugata McD.) (Lepidoptera: Lymantriidae), resulted in a 67 percent savings in man-hours when compared to obtaining comparable data by ground cruises. Ciesla et al.[10] reported the cost of aerial photographic surveys of southern pine beetle (D. frontalis (Zimm.)) to range from \$0.0023 to \$0.0077 per hectare (\$0.0055 to \$0.019 per acre), depending upon the size of the area surveyed.

This last qualifying statement, that cost depends upon the size of the area surveyed, initiated considerable interest in very small-scale (high-altitude) aerial photography. Heller et al.[11] stated that in general, as photographic scale decreases and infestation spot size decreases, photointerpretation accuracy decays accordingly. However, improved methods of multispectral image processing, both analog and digital, have been devised to aid the interpreter and improve accuracy. According to Heller et al.,[11]

> the potential for improved processing results will be achieved when multispectral scanners are available which provide for a common field stop for all channels, or at least a common instantaneous field of view, in the visible, near infrared and thermal infrared regime. . . . The availability of simultaneously registered data covering this entire bandwidth in narrowband increments should yield large improvements in accuracy. (p. 48)

On July 23, 1972, the first dedicated earth resources land-use satellite (LANDSAT-1) was launched. The spacecraft carries television cameras as well as radiometric scanners to obtain image data similar to that suggested as necessary by Heller et al.[11] The satellite circles the globe 14 times a day, 915 kilometers (494 miles) above earth, and is capable of sensing the same spot anywhere in the world at the same time of day, local time, every 18 days. The resulting photographs cover an area on the earth's surface approximately 189 kilometers (115 statute miles) square, with a resolution of about 80 meters (260 feet).[12] Therefore, the satellite affords the researcher the opportunity to analyze a sequence of both photographic and multispectral scanner data taken under uniform lighting conditions over a given area.

To analyze and test the utility of this new remote sensing data source, the National Aeronautics and Space Administration (NASA) has contracted with hundreds of investigators from other government agencies, industry, universities, and foreign governments. After just 7 months, the first "Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1" was held to give the users of LANDSAT data the opportunity to present the significant accomplishments of their investigations. Using LANDSAT-1 imagery and NASA underflights to detect damage by the mountain pine beetle (D. ponderosa Hopk.), Hall[13] reported that he could differentiate areas of heavy damage from those with little or no damage in the lodgepole pine type. Anderson et al.[14] reported that techniques have been implemented using LANDSAT-1 imagery of the Cook Inlet Basin to stratify damage to white spruce (Picea glauca), by the spruce beetle (D. obesus (Mann.)), into three levels—healthy, newly killed, and old killed. Rohde and Moore[8] used LANDSAT-1 imagery for the detection of fall cankerworm (Alsophila pomentaria (Harr)) (Lepidoptera: Geometridae) damage in a small forested area in Frederick County, Maryland. Using later LANDSAT-1 imagery, at or near the peak of gypsy moth defoliation, they found it possible consistently to identify areas of heavy defoliation and areas with no apparent defoliation. However, consistent detection of light and moderate defoliation classes in areas with no heavy defoliation was not demonstrated, and areas of defoliation were often confused with areas associated with mining activity and certain agricultural practices.

All of these investigators used photointerpretation of LANDSAT-1 images to detect damage, and therefore did not fully utilize the vast amount of data collected by the four-channel multispectral scanner. Since trees suffering varying degrees of defoliation will have different spectral signatures due to changes in the percentage of green vegetation present, LANDSAT-1 multispectral data and imagery, supplemented by good ground truth or aerial photography, should allow the detection of the various categories of defoliation: light (0-30%), moderate (30-60%), and heavy (60-100%). It was the intent of this project to test the effectiveness of using an integrated system, consisting of computer analysis and mapping, photointerpretation of LANDSAT-1 images, as well as underflight photography and ground truth, to detect more consistently and accurately gypsy moth defoliation in an efficient manner.

THE GYPSY MOTH

Since its introduction into the United States over 100 years ago, there has developed a considerable volume of literature on the gypsy moth. Perhaps the best overall and most up to date documentation of the gypsy moth appears in an annual volume published by the United States Department of Agriculture. The "Final Environmental Statement of the Cooperative Gypsy Moth Suppression and Regulatory Program—1974 Activities"[15] is the result of the combined efforts of several experts, and it was used as the main source of information in this section on the gypsy moth, except where otherwise noted.

The impact of gypsy moth on trees is well documented. Information is available on tree mortality, lost growth in trees, changes in forest stand composition, and, more recently, estimates of economic loss.

Gypsy moth caterpillars cause tree damage by devouring foliage. This feeding begins shortly after the caterpillars hatch from their eggs, generally in early May in Pennsylvania. Except where gypsy moth populations are unusually large, defoliation is not noticeable until early to mid-June. In

late June and early July the heaviest defoliation takes place as the caterpillars reach full size. Where defoliation is complete, trees may remain bare as late as early August, but in general, by mid-July hardwood trees that had about 60 percent or more of their foliage removed begin to refoliate. Studies indicate that hardwoods suffering less than 60 percent loss of foliage do not refoliate, and evergreens are not capable of refoliation.

The process of refoliation requires the use of stored energy, and after 2 years of defoliation these food reserves in the tree become critical. The result may be the outright death of the tree, or a gradual decline in vigor, possibly resulting in death, due to an increase in the tree's susceptibility to attack by organisms or other environmental extremes that ordinarily do not harm trees.

In a study on oak mortality in Pennsylvania, Nichols[16] found that a year of moderate defoliation reduced radial growth by 20 to 30 percent. But 1 year of heavy spring defoliation resulted in a 40 to 70 percent growth reduction. Later studies by Nichols[17] indicated that 2 consecutive years of 60 to 100 percent spring defoliation may kill about 30 percent of the oaks, and after 3 years of heavy defoliation the oak mortality may be 60 percent or more. Mortality of hardwood trees other than oak is expected to be less than 10 percent of their total number, while hemlocks and many pines and spruces completely stripped of their foliage will die in 1 year.

The rather obvious differences in tree mortality between the oaks and other hardwoods, and between hardwoods and conifers, is mainly due to the differences among varying tree species to withstand attack, and the differences in the food preferences of the gypsy moth larvae, both young and old. For example, aspen, basswood, larch, and all species of oak are among the tree species favored by all larval stages, while ash, black locust, poison ivy, sycamore, tulip poplar, and walnut are not favored by any larval stages. Other commonly encountered tree species in the eastern United States fall somewhere in between these two extremes as preferred food of the gypsy moth. Nichols[17] compiled a more complete list of the food preferences of the gypsy moth.

Information on the effect of gypsy moth defoliation on future stand composition is not abundant, but the larvae's preference for oaks seems to indicate a future reduction in the oak component in most stands. Some investigators feel that the defoliation benefits the red maple in the understory due to decreased competition for light and space, and an increase in available nutrients from frass manufactured at the expense of the oak. Whatever the long-term effect of the gypsy moth on forest stand composition may be, its immediate effect is a marked reduction in forest management options—often the only option is to salvage by clearcutting.

In an attempt to forecast expected timber losses, McCay and White[18] made an economic analysis of the gypsy moth problem in commercial forest stands in the northeast. They presented methods for calculating immediate and future losses in both pulpwood and sawtimber stands, as well as an average expected loss for each. For example, on the average the forest manager can expect a $1.88 loss per hectare ($4.65 loss per acre) in a pulpwood stand by the third year after 1 year of heavy defoliation. In a sawtimber stand, the immediate loss per hectare that may be expected from 1 year of heavy defoliation is $30.50 ($75.40 per acre), while total discounted future losses may exceed $46.58 per hectare ($115.10 per acre). Considering the number of acres infested by the gypsy moth, and the fact that much of this area is commercial forest land, financial losses will be sizable.

Payne et al.[19] did a similar type of economic analysis but applied to residential property. Guidelines were presented for determining dollar losses in residential property values from tree mortality caused by the gypsy moth. However, the effects on value from reduced tree vigor or the unsightly appearance of defoliated trees were not included. Their estimates of the value of residential trees were considerably higher than corresponding timber values. This fact led to an overall conclusion that more expensive and more selective control measures are justified for gypsy moth control in residential areas than in timber-producing areas.

PROCEDURE

Programs provided by the Office for Remote Sensing of Earth Resources (ORSER) of the Space Science and Engineering Laboratory (SSEL) and processed by an IBM System 370 Model 168 computer, both located at The Pennsylvania State University, were used in analyzing the LANDSAT computer compatible tapes (CCTs). The programs are fully described in a users' manual.[20]

Digital processing of remote sensed data requires the use of an iterative procedure. A test area, generally selected because of the availability of ground truth data, is processed and the results are compared with ground truth. Successive refinements in classification techniques are then followed until a satisfactory match between the computer-produced maps and ground truth is obtained. A much larger area is then processed to test the generality of the technique. Due to the iterative nature of this process, there is no clear differentiation between procedure and results, so that the distinction which is made in this, and the following section is largely arbitrary.

The woodlands of Pennsylvania offer the unique situation of widespread similarity of tree species at differing degrees of gypsy moth infestation. Initially, however, it was decided to concentrate on the forests of the northeastern portion of Pennsylvania for two main reasons: (1) the existence of vast acreages of varying degrees of gypsy moth defoliation in this region, and (2) the availability of ground truth information in the form of color infrared (IR) aerial photography at a scale of 1:6000 (taken July 18, 1973) and data gathered in the field by the Pennsylvania Bureau of Forestry (BOF) and the U.S. Forest Service (USFS).

The acreage and severity of gypsy moth defoliation reaches a peak from mid-June through the first few days of July. If the defoliation has only been light to moderate in past years, the deciduous trees will respond with a new canopy of leaves by mid- to late-July.[15] For this reason, the timing of aerial coverage and ground support data is extremely important. LANDSAT-1 coverage of northeastern Pennsylvania on July 8, 1973, fell on a cloud-free day, and LANDSAT-1 scenes 1350-15183 and 1350-15190 proved very satisfactory for visual and computer analysis.

The first step in computer processing was to develop work tapes containing the digital data from those portions of the scenes where gypsy moth damage was known to have occurred. Two aids were used in deciding which scene portions would make good study areas: the "Forest Pest Report,"[3] which gave a county-by-county summary of total defoliation for both 1972 and 1973; and the LANDSAT-1 images themselves. Image reproductions of MSS band 7 showed defoliation as dark gray. Healthy vegetation appeared as lighter shades of gray, while black represented water bodies (Figure 1). The SUBSET program was used to transfer the desired data from the original NASA LANDSAT tapes to a work tape. This program also converts the tape format to a standard ORSER format.

Once the desired portions were subsetted, proper location and orientation on the tape, pertaining to the areas of interest on the ground, had to be achieved. The NMAP program was used for this purpose. This program uses all four channels of the LANDSAT data to map element brightness averaged over these channels. Output from the program consisted of a brightness map. Certain symbols were assigned to various percentage intervals of brightness and the patterns of symbols were helpful in interpretation. Water bodies were extremely helpful for orientation purposes due to their low brightness, uniformity, and distinctive spectral signature. Northeastern Pennsylvania has numerous lakes and swamps large enough in size to show up on LANDSAT-1 images. A complete supply of U.S. Geological Survey (USGS) 7.5 minute topographic maps of the study areas proved to be invaluable in substantiating accurate identification of water bodies.

After the proper areas had been subsetted and orientation within these areas achieved, the combined tasks of classification and character mapping were undertaken. Two different paths were available at this point—the supervised or unsupervised classification procedures. The unsupervised classification, or cluster analysis, procedures were chosen, with the intent of using the supervised procedures

at a later date to check for uniformity as well as variability in the spectral signatures obtained from cluster analysis.

The majority of spectral signatures used throughout the project were developed using the DCLUS program. In using this program, one specifies the corner coordinates of the target area(s) to be processed, the number of sample points to be chosen initially, and the initial critical clustering distance. Output consists of a list of spectral signatures corresponding to the mean vector length and standard deviation. A character is assigned to each cluster spectral signature and a character map of the specified target area(s) is output.

RESULTS*

The discussed method of developing spectral signatures was initially applied to two different study areas. A section of Blue Mountain, located near Auburn, Pennsylvania, on the Schuylkill-Berks County line, and represented on LANDSAT-1 scene 1350-15190, was chosen for analysis because the areal extent of defoliation was adequate, yet somewhat isolated from the extensive defoliation to the northeast. A second area, north of East Stroudsburg, Pennsylvania, in Pike County, encompassed three experimental plots aerially sprayed with the chemical insecticide Dylox. These plots were easily identifiable on LANDSAT-1 image 1350-15183 due to their peculiar shapes and orientation.

A lack of ground truth data resulted in the abandonment of the Blue Mountain study area. On the other hand, ample ground truth data were available as an aid in analyzing the area surrounding the Dylox spray plots. With the help of color IR aerial photography, and other supporting ground truth information, classification of the spectral signatures into categories was not difficult. It was apparent that defoliated trees had lower responses in MSS bands 6 and 7, with the degree of response depression corresponding to the severity of defoliation. Initially, 10 categories were delineated and used as input in the more sophisticated classification program DCLASS.

DCLASS allows the user to input spectral signatures obtained from DCLUS or certain other ORSER programs. The euclidean distance of separation between an element vector and each of the category vectors is used to assign the element to the category to which it is closest. If the element is distant from every category by more than the user-assigned critical distance, it is classified as "other."

The standard deviations, in distance units, from DCLUS were used as a guide for setting the critical distance in DCLASS. An initial critical classification distance of 8.0 was used. Mapping symbols were assigned to each category and character maps were generated. Further refinements in category specification were made possible as familiarity with the target areas increased. Eventually, a total of 31 categories were separated through continued use of DCLUS and DCLASS.

In addition to character maps, DCLASS outputs frequency distributions for all categories and distances of separation between all pairs of spectral signatures. Of the 31 signatures, there were 9 for lakes and swamps, 10 for healthy vegetation, 5 for defoliated forests, and 7 for miscellaneous categories. The frequency distribution table indicated that the signatures assigned category symbols to 98 percent of the study area, leaving only 2 percent unclassified.

The table of distances of separation revealed that the distance among spectral signatures within the set of 5 categories for heavy defoliation and within the set of 10 categories for healthy vegetation were much less than the distance between category sets. Within the 5 categories for heavy defoliation, the average distance of separation was 2.89, with a range of values from a low of 0.90 to a high of 4.20. Within the 10 categories for healthy vegetation, the average distance of separation was 4.10, with a range of values from 0.80 to 9.00. The higher average and greater range of values for healthy

*A portion of these results has been previously reported in Williams and Turner.[21] All analytical work was carried out by the senior author.

vegetation were not surprising, as one would expect greater heterogeneity in spectral signatures due to the number of different deciduous and coniferous species found in the mixed forests of Pennsylvania. On the other hand, one would expect better overall similarity among spectral signatures for denuded woodlands, as the forest floor and bare branches would reflect roughly the same amount of radiation regardless of tree species.

With this in mind, it was decided to average the 5 spectral signatures for heavy defoliation to get 1 overall signature for this category. The same was done with the 10 spectral signatures for healthy vegetation. Thus, the total number of categories was trimmed from 31 to 11. This cut the costs of generating character maps, while sacrificing little accuracy.

DCLASS, using 11 categories, generated a character map which closely resembled previous maps when all 31 categories were specified. The greatest change occurred in the percentage that was unclassified. It increased from 2 to 7 percent. However, the distance of separation between the category for heavy defoliation and that for healthy vegetation was 12.7. When the initial critical classification distance of 8.0 was increased to 10.0, the percentage unclassified was reduced from 7 to 3 percent.

As a first approximation to obtaining a category for moderate defoliation, a spectral signature midway between that for heavy defoliation and healthy vegetation was obtained by averaging their spectral signatures, thus differing from each by 6.3 units. This signature was refined after comparing character maps with estimates of defoliation on ground photos.

Table I is a list of the 12 categories delineated within the study area, including a summary of the symbols assigned to each category and their spectral signatures. It should be noted that channel numbers 1, 2, 3, and 4 correspond with MSS bands 4, 5, 6, and 7. The signatures of particular interest are those for heavy defoliation (10), healthy forest (11), and moderate defoliation (12). Although these 3 categories show similar responses in channels 1 and 2, substantial differences in response can be seen in channels 3 and 4, corresponding to the degree of defoliation. "Healthy forests" is considered to have approximately 0-30 percent defoliation; "moderate defoliation," 30-60 percent; and "heavy defoliation," 60-100 percent defoliation.

Figure 2 is a picture of the Dylox spray plots as derived from BOF maps and color IR aerial photography. These plots not only offered good reference points, but were most helpful in the development of spectral signatures as all defoliation levels were represented. Those areas receiving maximum spray application were relatively unharmed and healthy, while the surrounding unsprayed forest land was generally heavily defoliated. Inadequate application of the Dylox spray caused certain areas within and around these plots to show moderate degrees of defoliation.

A character map produced by the classification program DCLASS from the spectral signatures given above shows the three sprayed plots in the lower half of the figure (Figure 3). The total area represented in the figure is approximately 6,475 hectares (16,000 acres). Character maps such as these are useful as work maps for the user in his analysis of MSS data. However, they are inherently distorted in the length to width relation because of the fixed number of lines and characters per inch on line printers.

These results indicated that LANDSAT-1 data could be used to discriminate between defoliated and healthy vegetation in northeastern Pennsylvania and that the digital processing methods developed by ORSER could be used to map the extent and degree of defoliation. Next, it was necessary to determine if the spectral signatures developed in northeastern Pennsylvania could be used to detect defoliation in other parts of the state.

Some 5,260 hectares (13,000 acres) of woodland near Aaronsburg and Woodward, in eastern Centre County, were defoliated in varying degrees by the gypsy moth in 1973. Since most of the defoliation was moderate and rather scattered in occurrence, it was not as easily detectable visually on LANDSAT-1

scene 1350-15190 as the vast amount of heavy defoliation that occurred in the eastern counties. In fact, a photointerpreter may have overlooked it entirely if he had no previous knowledge that defoliation had occurred there. It was decided to use the spectral signatures developed earlier from both LANDSAT-1 scenes as input into the DCLASS program to see if the Centre County defoliation would be detected.

The DCLASS map of the Centre County defoliation compared very well with a sketch map obtained via aerial reconnaissance, but certain discrepancies were noted in the classification of degrees of defoliation. For instance, the majority of the areas classified as heavy defoliation on the sketch map were classified as moderate defoliation on the computer-generated maps. There are two possible explanations of this discrepancy and both are related to the timing of the surveys. LANDSAT-1 coverage occurred on July 8, 1973, while the aerial reconnaissance for sketch mapping was done on July 23, 1973, roughly 2 weeks later. This seemingly small difference in time can be very important in the development of insect populations, or other biologically or climatically controlled phenomenon. For example, Hopkin's Bioclimatic Law states that for every 1° change in latitude north, every 5° change in longitude east, or every 400-foot increase in elevation, there is a 4-day delay in development.[22] Using this as a guideline, it can be estimated that biological development in Centre County, such as the leafing of trees and the hatching of insect eggs, etc., should occur approximately 10 days later than in eastern Pennsylvania. Therefore, heavy defoliation would be unlikely in Centre County on July 8, as the later and most damaging instars of the gypsy moth would not have developed at that time. By July 23, however, heavy defoliation would have occurred in the areas of dense insect populations.

A second possibility, one that must always be considered when using data based on human judgment, is the inherent variability in judgment decisions. As indicated previously, it is easily possible that what one observer calls heavy defoliation could be called moderate by another observer. That is why it is important to devise a system with an unbiased decision rule such as spectral characteristics interpreted by a computer program.

Another area of interest, and possible confusion, was briefly investigated. The ability to discriminate between defoliated trees and trees killed as a result of previous defoliation would greatly aid those responsible for preparing impact statements, or those interested in the early detection of salvageable stands. By comparing data obtained at the time of defoliation with data from a LANDSAT-1 pass later in the summer after refoliation, it was hoped that nonrefoliating or dead trees could be detected.

LANDSAT-1 scene 1404-15175 provided good coverage of eastern Pennsylvania on August 31, 1973. It covered the same area as the July 8, 1973, scene 1350-15183, and in particular, the area surrounding the Dylox spray plots. A thorough step-wise investigation of the digital data, similar to that described in earlier parts of this chapter, was performed, but no spectral signatures were obtained that would indicate dead trees (i.e., low responses in MSS channels 6 and 7). An attempt was also made to recalibrate the August digital data to the July standards, using the RECAL program, so that the July spectral signatures could be better utilized. However, the two scenes were so different spectrally due to the lack of foliage in July and the abundance of foliage in August, that the recalibration process was unsatisfactory.

Further investigation, including personal communication with people familiar with the gypsy moth problem in Pennsylvania, failed to result in the location of any large areas of forest totally killed by gypsy moth. Since the resolution of LANDSAT-1 is much greater than the crown area of individual trees, scattered tree mortality would not be detectable because dead trees could be obscured by surrounding foliage.

CONCLUSIONS

These results have indicated that LANDSAT-1 data can be used to discriminate between defoliated and healthy vegetation in Pennsylvania and that the digital processing methods developed by ORSER can be used to map the extent and degree of defoliation. However, a critical factor in any defoliation

detection and mapping scheme is timing. All data must be collected after the peak of feeding by the larvae and before refoliation begins. At most, this period is 2 or 3 weeks.

Present survey methods, which rely heavily upon aerial survey from light aircraft, have several limitations. Although they can provide timely data related to the extent of defoliation, the precision of mapping is inherently affected by the observer's knowledge of the local geography and his ability to relate this to what he sees from the air. In addition, the necessity of covering vast areas in a short time span requires the use of several observers, and differences between each observer's interpretations may be substantial.

On the other hand, LANDSAT-1 data, when analyzed by a computer, can result in the production of maps which are not subject to operator bias. The problem of changes in the forest canopy during the survey are negated since substantial areas, covering entire watersheds or states, can be monitored in one day. Computer-generated maps allow for a more precise location of boundaries, and area estimates are obtained as a by-product.

However, there are several problems associated with relying solely on LANDSAT-type satellites for detection programs. The most serious limitations are associated with the frequency of passes. The satellite covers a given area only every 18 days, which is roughly the length of the critical feeding stage in the life cycle of the gypsy moth. In addition, there is a greater than 50 percent probability in this part of the country that cloud cover will be present on a given overpass. There is therefore a high possibility that adequate coverage will not occur when defoliation is at its optimum detection stage. These timing problems could be alleviated in the future if more satellites were in orbit, thus allowing for more frequent coverage. Another limitation of LANDSAT-1 imagery is its resolution of 60 to 90 meters (200 feet to 300 feet), making it appropriate for detecting only widespread defoliation or mortality over large areas.

At present, the best use of LANDSAT-1 data seems to be the unbiased detection and mapping of the areal extent of the various defoliation categories. Continued research, supplemented by more frequent coverage and faster dissemination of monitored data, may result in a system which provides rapid and accurate means of detection and mapping of insect defoliation in forests.

ACKNOWLEDGMENTS

The author wishes to acknowledge Dr. Brian J. Turner for the guidance he provided throughout this study. Appreciation is also extended to Dr. F. Yates Borden and Dr. E. Alan Cameron, as well as Dr. Turner, for their constructive criticisms of and comments on this paper.

The author would like to thank personnel of the Office for Remote Sensing of Earth Resources of the Space Science and Engineering Laboratory at The Pennsylvania State University for supplying many of the materials and equipment used in analyzing the project data. Mr. T. Doman Roberts of the Advanced Technology Applications Corporation is to be thanked for loaning ground truth information which proved to be a very helpful aid in analyzing certain computer-generated maps.

The School of Forest Resources, The Pennsylvania State University, has supplied financial aid for this project and the author wishes to acknowledge this aid as being invaluable.

REFERENCES

1. Baker, W. L. 1972. Eastern Forest Insects. U.S.D.A. Forest Service, Misc. Publ. No. 1175. U.S. Govt. Printing Office, Washington, D.C. 642 pp.

2. Graham, S. A. and F. B. Knight. 1965. Principles of Forest Entomology. McGraw-Hill, Inc., New York, N.Y. 417 pp.

3. Nichols, J. O. 1973. Forest Pest Report—July 1973. Pa. Dept. of Environmental Resources, Bur. of Forestry, Harrisburg, Pa. 3 pp.

4. Rohde, W. G. and H. J. Moore. 1974. Forest defoliation assessment with satellite imagery. Proceedings of 9th International Symposium on Remote Sensing of the Environment. ERIM. Ann Arbor, Mich. pp. 1089-1104.

5. Croxton, R. J. 1966. Detection and Classification of Ash Dieback on Large Scale Color Aerial Photographs. U.S. Forest Service, Pac. S. W. Forest and Range Expt. Sta., Res. Paper PSW-35. Berkeley, Calif. 13 pp.

6. Wert, S. L. and B. Roettgering. 1968. Douglas fir beetle survey with color photos. Phot. Eng. 34: 1243-1248.

7. Bousfield, W. E. 1973. Estimating losses caused by the Douglas-fir beetle in the northern region. IN: Management and Utilization of Remote Sensing Data, Proceedings of a Symposium on Remote Sensing. Abraham Anson, Editor. American Soc. of Photogrammetry, Falls Church, Va. pp. 557-563.

8. Rohde, W. G. and H. J. Moore. 1973. Evaluation of gypsy moth (Porthetria dispar) damage with remote sensing techniques. Proceedings of 4th Aerial Color Workshop in the Plant Sciences, Orono, Maine.

9. Wert, S. L. and B. E. Wickman. 1970. Impact of Douglas-fir Tussock Moth . . . Color Aerial Photography Evaluates Mortality. U.S.F.S., Pac. S. W. Forest and Range Expt. Sta., Research Paper PSW-60. Berkeley, Calif. 6 pp.

10. Ciesla, W. M., J. C. Bell, Jr. and J. W. Curlin. 1967. Color photos and the southern pine beetle. Photo. Eng. 33: 883-888.

11. Heller, R. C., F. P. Weber and K. A. Zealear. 1970. The Use of Multispectral Sensing Techniques to Detect Ponderosa Pine Trees Under Stress from Insects or Diseases. Annual Progress Report, For. Remote Sensing Lab. for Nat. Resource Prog., U.S.D.A., Pac. S. W. Forest and Range Exp. Sta., Berkeley, Calif. 50 pp.

12. NASA. 1972. Data Users Handbook—NASA Earth Resources Technology Satellite. Document No. 71SD4249. NASA, Greenbelt, Md.

13. Hall, R. C. 1973. Application of ERTS-1 imagery and underflight photography in the detection and monitoring of forest insect infestations in the Sierra Nevada Mountains of California. Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1, Vol. 1, Section A. NASA, Greenbelt, Md. pp. 135-142.

14. Anderson, J. H., F. P. Weber, J. M. Miller, E. Becia and R. C. Beckwith. 1973. Impact of ERTS images on surveys of forest insect infestation in Cook Inlet Basin, Alaska. Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1, Vol. 1, Section A. NASA, Greenbelt, Md. p. 143.

15. Anonymous. 1974. Final Environmental Statement of the Cooperative Gypsy Moth Suppression and Regulatory Program—1974 Activities. U.S.D.A., USFS and APHIS, Washington, D.C. 178 pp.

16. Nichols, J. O. 1961. The Gypsy Moth in Pennsylvania. Pa. Dept. of Agr., Misc. Bulletin No. 4404. Harrisburg, Pa. 82 pp.

17. Nichols, J. O. 1973. The Gypsy Moth. Pa. Dept. of Environmental Resources, Harrisburg, Pa. 16 pp.

18. McCay, R. E. and W. B. White. 1973. Economic Analysis of the Gypsy Moth Problem in the Northeast; I. Applied to Commercial Stands. U.S.D.A. Forest Service Research Paper NE-275. Upper Darby, Pa. 9 pp.

19. Payne, B. R., W. B. White, R. E. McCay and R. R. McNichols. 1973. Economic Analysis of the Gypsy Moth Problem in the Northeast; II. Applied to Residential Property. U.S.D.A. Forest Service Research Paper NE-285. Upper Darby, Pa. 6 pp.

20. Borden, F. Y., D. N. Applegate, B. J. Turner, H. M. Lachowski and J. R. Hoosty. 1973. ERTS and Aircraft Multispectral Scanner Digital Data Users Manual. ORSER-SSEL Tech. Report 11-73. The Pennsylvania State Univ., University Park, Pa. 235 pp.

21. Williams, D. L. and B. J. Turner. 1974. Computer analysis and mapping of gypsy moth defoliation levels in northeastern Pennsylvania using ERTS-1 data. IN: Remote Sensing of Earth Resources, Vol. III. F. Shahrokhi, Editor. Univ. of Tennessee Space Inst., Tullahoma, Tenn. pp. 487-502.

22. Hopkins, A. D. 1920. The bioclimatic law. J. Wash. Acad. Sci. 10: 34-40.

TABLE 1. - MEAN SPECTRAL SIGNATURES AND MAPPING SYMBOLS DERIVED FROM DCLASS OUTPUT

Category Name	Number	Symbol	Critical Distance	Unnormalized Category Specifications			
				Channels[1]			
				1	2	3	4
Water	1	=	10.0	27.83	19.00	17.25	5.21
Wetlands	2	-	10.0	33.60	24.00	31.00	14.00
Swamp1H20	3	=	10.0	32.51	22.77	24.67	9.90
Lake-edge	4	-	10.0	32.50	22.75	32.75	15.00
Siltwater	5	=	10.0	35.60	24.93	21.57	6.74
Swamp2H20	6	=	10.0	33.32	24.26	26.71	11.31
Swamp3H20	7	=	10.0	31.63	21.46	22.33	8.61
Swamp4H20	8	=	10.0	33.02	22.98	21.02	5.23
Swamp5H20	9	=	10.0	29.03	19.22	23.67	9.25
Heavy Defoliation	10	@	10.0	34.08	25.47	41.30	21.08
Healthy Forest	11	I	10.0	34.79	24.61	51.47	28.52
Moderate Defoliation	12	+	10.0	34.44	25.04	46.38	24.80

[1]Channels 1, 2, 3, and 4 correspond with MSS bands 4, 5, 6, and 7.

Figure 1. - A blowup of a portion of MSS band 7 from LANDSAT-1 scene 1350-15183, July 8, 1973. (Water appears black, defoliation appears as darker shades of gray, and h-althy vegetation appears as lighter shades of gray. T.. area inside the box includes Dylox spray plots represented in other illustrations.)

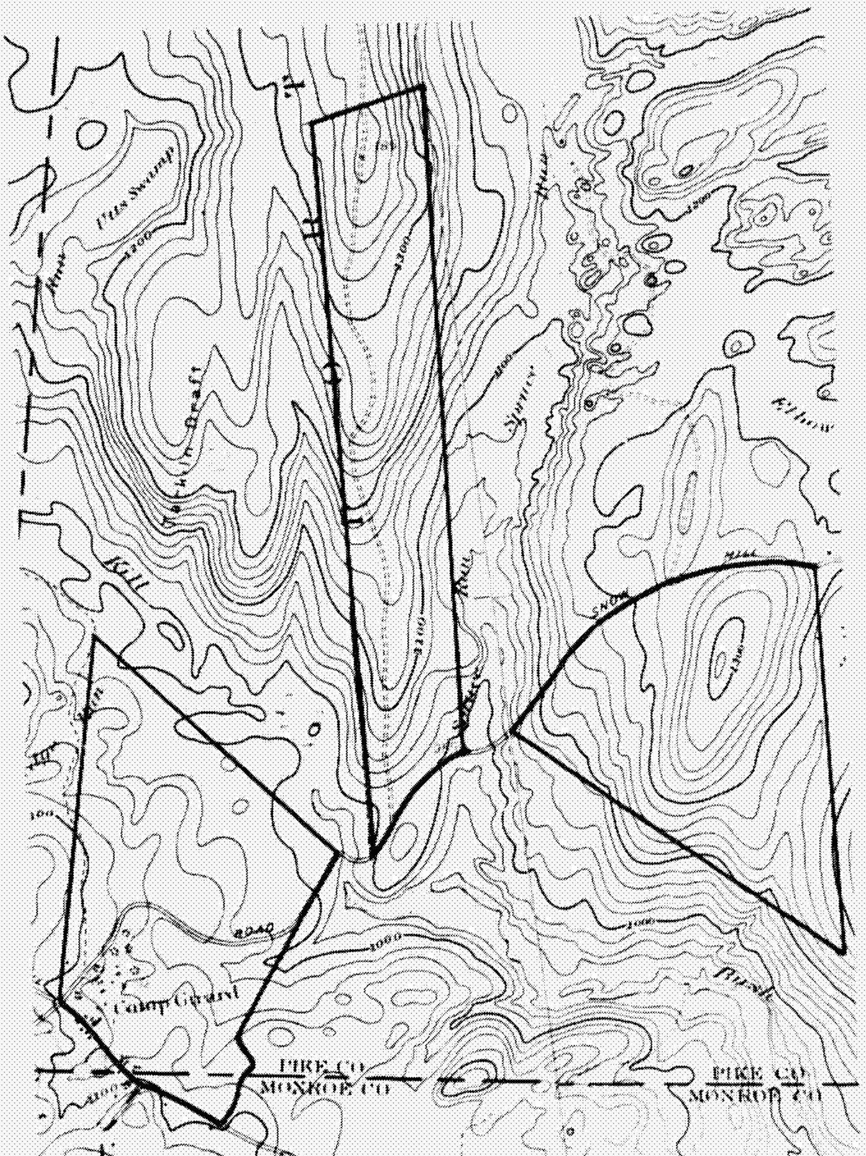
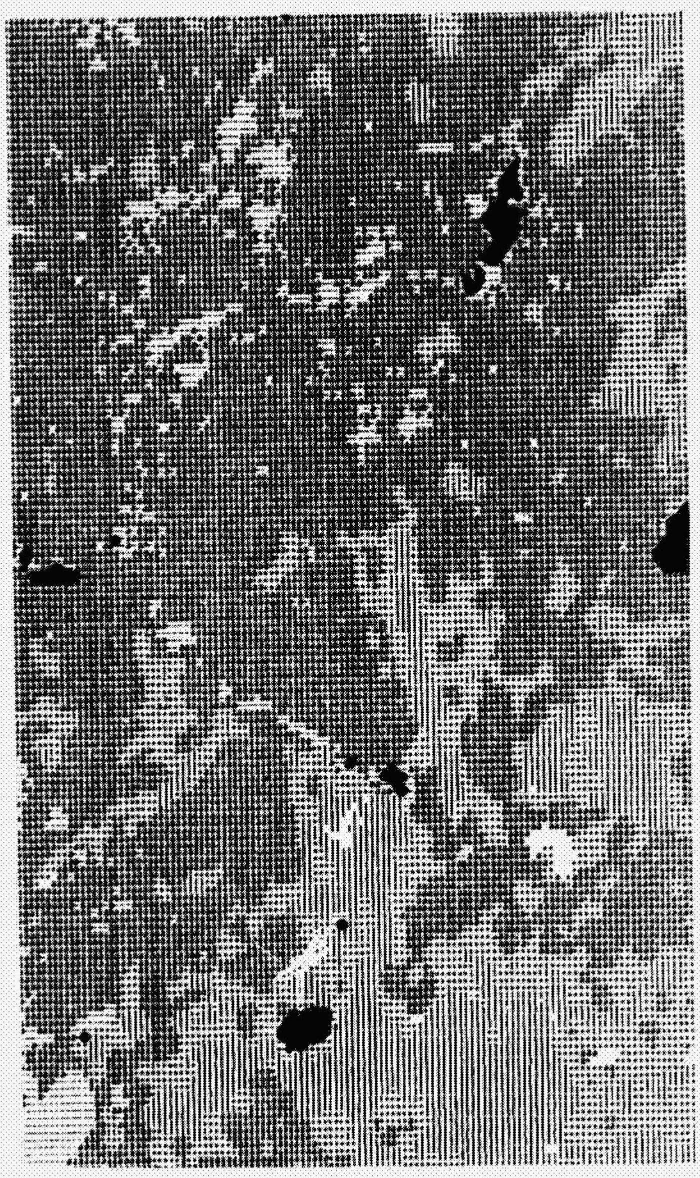


Figure 2.- Picture of Dylox spray plots showing shape and orientation.



LEGEND

Heavy Defoliation	@
Moderate Defoliation	+
Healthy Forest Land	I
Wetlands	-
Water	"dark"

Figure 3. - Character map derived from DCLASS using spectral signatures given in Table 1. (Dylox spray plots appear in lower half.)

A-14

COMPUTER IMPLEMENTED CLASSIFICATION OF VEGETATION USING AIRCRAFT ACQUIRED MULTISPECTRAL SCANNER DATA

By William G. Cibula, NASA/JSC, Earth Resources Laboratory
Bay St. Louis, Mississippi

N76-17482

ABSTRACT

The use of aircraft 24-channel multispectral scanner data in conjunction with computer processing techniques to obtain an automated classification of plant species associations will be discussed. The classification of various plant species associations will be related to information needed for specific applications.

In addition, the necessity of multiple selection of training fields for a single class in situations where the study area consists of highly irregular terrain will be detailed. A single classification will be illuminated differently, in different areas, resulting in the existence of multiple spectral signatures for a given class. These different signatures result since different qualities of radiation upwell to the detector from portions that have differing qualities of incident radiation. Techniques of training field selection will be outlined, and a classification obtained from a natural area in Tishomingo State Park in northern Mississippi will be presented.

INTRODUCTION

From earliest times man has chosen to settle in the vegetated regions of the earth because they best provided for the needs of man. For the most part, this is still true today.

It is the radiant energy which is reflected or radiated from this vegetational cover that is monitored in the acquisition of remotely sensed data from either aircraft or spacecraft over these land areas. This plant cover can either be partially or wholly natural, such as in some of our parks and forests, or it may be plant types which exist solely as a result of man's intervention such as farmlands.

The plants that are to be found in a given area depend upon many local environmental conditions such as soil types, rainfall, frost-free period, etc. This aspect is well known to plant ecologists and agronomists alike, and is generally understood by the public. For example, one would not expect to successfully farm cotton in Alaska. Less well understood are interactions of other aspects of the ecosystem which can be determined through vegetational parameters. As an example, in the marshlands to be found along the Gulf Coast, the salt marsh moquito Aedes sollicitans breeds, and oviposits on soil that at the time of oviposition is not covered by water but is periodically inundated by tidal action within these wetlands. These sites of probable oviposition can be determined by (plant) vegetational associations as found in different hydric regimes. As these associations can be separated and classified when multispectral scanner (MSS) data is properly processed, these oviposition sites can be determined through the identification of the plant associations that are found thereon.

Table I gives a few examples of some applications of vegetational analysis, where this analysis is based on the acquisition of remotely sensed data.

The purpose of this paper is twofold. One will be to outline several criteria which must be understood and employed in training field selection where differing physical factors within the site dictate the necessity of multiple training field selection for a single class or association to be properly identified. The second purpose will be to detail several applications of inferential classifications derived from plant association analysis and to discuss several of these in some depth to better acquaint the reader with the potential of the inferential method.

RECOGNITION OF PHYSICAL FACTORS AFFECTING TRAINING FIELD SELECTIONS

Shortly after the organization of the Earth Resources Laboratory (ERL), the problem of determining the possibility of classifying marsh vegetation arose. This inquiry was the direct result of interest by local mosquito abatement districts and by various state agencies responsible for management of wetland resources. The details of mapping vegetational associations to infer high mosquito oviposition risk sites is covered elsewhere (Cibula 1972).

The coastal marshlands found in part of Louisiana and Mississippi are part of an extensive alluvial plain which is an older portion of the Mississippi Delta. This plain, which has little relief, slowly drops toward the Gulf, and is close to sea level over most of its extent.

The plants which are found in the marsh are often considerably smaller than the resolution cell obtained from scanner data. This criterium even holds for MSS data obtained from 1220m where an individual element is approximately being 2.5 X 2.5 meters (8' X 8'). As this is the case, in the marsh one often finds that an element will contain a number of individual plants--in many cases of differing species such as a mixture of *Juncus roemerianus* and *Spartina patens*. Additionally, the shadows of the plants also often fall within the element. The lack of relief in the marsh contributes to extremely uniform illumination over very extended areas. Consideration of all these factors produces integrated signatures from each element - often the element producing a signature of an associational complex. Taken in total, all the elements from a well chosen training field yield well defined statistics with relatively small divergences. In practice, the associations in the marsh often separate well from each other.

In upland areas, the situation described above often does not hold. In dissected terrains, it is not unusual to find a particular association on both sunlighted and shadowed sides of ridges. Such a situation was encountered in a study area in north Mississippi. Tishomingo State Park (Figures 1 and 2) was chosen for a low altitude 1220 meters (4000') MSS flight to determine the effect of terrain dissection on plant species association classifications. Figure 3, from an RC-8 color infrared photograph taken simultaneously with acquisition of MSS data shows the diversity of illumination types to be found. This mission, one of a series planned over this area at differing seasons, was flown in January. The primary purpose of this study was to determine the efficiency of processing MSS data obtained in the winter season to separate pine from hardwood. The application to rapid, large area forest inventory is obvious.

Since it was recognized that illumination on pine, hardwood, etc. when on the shadowed side of a ridge differed in both quantity and quality from these same associations on a sunlighted slope, multiple training fields were taken of each association. These separate training fields for each class under differing illumination conditions were treated as separate classes during classification, but were

color coded the same color when the display was prepared. The result of several classifications over a restricted area is shown in Table II. As a comparison, this same area was photo interpreted and a random dot pattern was used to produce the acreage calculations. From these acreages for each class, the percentages of the total acreage for that class were calculated. For the MSS classifications, a program to compile acreages for each class was used.

Two obvious discrepancies are obvious in MSS classification I. The percentages classified for water and for pine were low. Inspection of the classified product showed that the error in water classification resulted as much of the water (river, lake edges) was in partial or full shadow. Choosing additional water training fields from representative shadowed areas, minimized the problem. This is shown with classification II. (See Figure 4)

The situation with pine was somewhat different. From the table, it is evident that the difference between the classified pine and the pine which should be classified shows up primarily in the classified category.

Field studies in areas of high disjuncture for pine classification revealed that the pines which are unclassified are primarily individual pines scattered among hardwoods -- a common feature of the Oak-Pine forest region (Braun, 1950).

Further field analysis of these situations revealed that many of these pine were open crowned. Coupled with this, as the mission was flown at a time of year when the sun angle is low, the shadow of the crown fell off to one side, well away from the base of the tree. This meant that the understory beneath the pine was sunlighted as the neighboring deciduous trees were leafless. As a result of both the open crowned aspect of these trees, and the illumination of the forest floor beneath these crowns, the spectral signature seen by the scanner was a composite of the signature from the pine and that of the forest floor, yielding a signature different from any of the chosen classes. Hence, these pines recorded as unclassified.

To rememdy this situation, it was necessary to select very small training fields from over a number of these individuals, such that there would result a sufficient number of elements to produce reliable statistics. This has been accomplished, and will be reported in the future.

INFERENTIAL CLASSIFICATIONS

Xeric vs. Mesophytic sites: Longleaf pine (*pinus palustris*) is commonly found along the coastal plain in the southeast. Generally, this pine is found growing on soils which characteristically are low in organic matter (Fowells, 1965). Within these constraints, on sandy, well drained and therefore xeric sites, turkey oak, blue-jack oak, sand post oak and saw palmetto are found. On moister, and therefore more mesophytic sites, dogwood is one of the common understory components with longleaf. Classification and identification of these understory components, also allow the identification and location of these two differing site types.

Fusiform Risk Zones: Fusiform rust (*Cronartium fusiforme*) an important fungal pathogen to pines in the south, cannot be transmitted from pine to pine. This fungus requires an alternate host to complete its complex life cycle.

Aeciospores produced by this fungus in infected pine, are released in the spring. These spores are carried by wind and air currents to oaks, where they germinate on the leaves (Czabator, 1971). About 20 to 35 days after germination of the aeciospore on

the oak leaf, the fungus produces telia on the lower surface of the oak leaf. The telia produce teliospores which soon germinate to produce sporidia. It is the sporidia which carry the infection from the oak to the pine. The sporidia are very sensitive to adverse conditions and quickly lose their capacity to initiate an infection. As a result, the maximum distance they can travel from an oak to infect a pine is not great.

An ERL project is currently in progress in cooperation with personnel from the Gulfport station of the Southern Experiment Station, USFS. Personnel at the Gulfport Field Station are engaged in research to quantify the distance relationship between oak and pine to the probability of sporidial infection. Analysis of aircraft MSS data is in progress at ERL. At this writing, it has been demonstrated that oak can be separated and classified from other forest species (See Figure 5). The classification of oak will be used to generate a map which will relate a particular area to the probability of infection if pine is planted on that site.

RECOGNITION OF STRESS AND STRESS RELATED PARAMETERS

Plants under stress exhibit spectral signatures which are different from the signature of these same species which are not stressed (Weber & Polcyn, 1972). Stress due to disease is what most often comes to mind when one considers a situation where a plant may be stressed.

In this paper, I present another aspect of stress--that due to mycorrhizal insufficiency and how remote sensing can be used to identify these stressed areas. The mycorrhizal relationship is one of a symbiotic relationship in which the smallest order of secondary roots of a tree are invaded by specific fungi during periods of active root growth (Hacskaylo, 1972). Without mycorrhizae, many plants (including especially important forest species) could not survive in the high competitive biological communities found in natural soil habitats.

With reference to Southern Pine, this relationship is dramatically shown by studies of Vozzo (1971). In this study, slash pine were grown in a situation where the mycorrhizal relationship was not allowed to be established. This is shown in Figure 6.

At the same time, a second group of slash pine were inoculated with mycorrhizal fungi during the second year of growth. At the end of a 5-year period, the growth of these inoculated trees in shown diagrammatically in Figure 7. These two extremes show the marked benefit of this relationship for southern pine. In a competitive environment, the pine in which this relationship was not at all established would not be able to compete and as such would not survive. Under natural conditions, mycorrhizae are usually found within all forest areas, but the degree of involvement shown with respect to the quantity and speciation varies greatly.

Where this relationship is developed to the maximal extent, we have maximal growth of pine, where this relationship is minimal, we have poor growth and a condition of increased stress with these pines.

The reason for this stressed condition in areas of low mycorrhizal incidence is that the fungal partner in this relationship where established, assists the trees in nutrient update, increases solubility of minerals from soils that are necessary for trees, helps to protect roots against pathogens, moves carbohydrates from one plant to another, produces plant growth hormones and by the coupling of the mycelial network

of the fungus to the tree roots, one finds a greatly increased surface area available for water uptake (Hacskaylo, 1972). This is especially important in times of drought.

If areas could be found where there exist differing degrees of mycorrhizal involvement, it would then be possible to select these areas as training fields for possible separation by the use of the technique of computer automated classification of multispectral data. These separations would, of course, be based on the presently assumed differences in spectral signature resulting from the differences in the degree of mycorrhizal involvement. These differences in spectral signature might well arise from differing stresses that would be found in these different areas.

Since the training fields needed would be relatively large (at 1200 meters, one would need 30 x 30 m. training fields), finding areas of such size that differ in mycorrhizal involvement would appear to be quite improbable, however, one such area was located within the Harrison Experimental Forest, north of Gulfport.

The Harrison Experimental Forest is located about 20 miles north of the Mississippi Gulf Coast (Figure 8). One of the projects currently under investigation is a fertilization study involving the three species of southern pine: slash, loblolly and longleaf pine. The area had been stocked with second growth longleaf pine before it was clear cut in 1959. The soils are upland fine sandy loams in the Bowie and Shubuta agricultural series and are low in nitrogen, phosphorus and potassium.

The slash pines were open pollinated progenies from two groups of five parents each. The loblolly pines were open pollinated progenies from one group of five parents and from a second group of two parents. For each of the pines, the two groups were distinguished on the basis of specific gravity; one group having wood of high specific gravity while the second group had trees whose wood was of average specific gravity.

For the three species, equal amounts of seed from parents within each group were mixed before sowing in a nursery. The one year old seedlings were lifted and row planted at 10 X 10 foot spacings in February and March 1960. Plots consisted of 100 trees surrounded by two rows of border trees and were arranged in four replications. The 10 treatments (the two wood density classes and five cultural treatments) were completely randomized within each replication as shown in Figure 9. The treatments given for each species and each wood density class within each species on each of the four replications are as shown on the following Table:

TABLE III. FERTILIZATION TREATMENT

1) Cultivation, no fertilization.
2) Cultivation with 100 lbs N, 50 lbs P_2O_5 and 50 lbs K_2O/acre.
3) Cultivation with 200 lbs N, 100 lbs P_2O_5 and 100 lbs K_2O/acre.
4) Cultivation with 400 lbs N, 200 lbs P_2O_5 and 200 lbs K_2O/acre.
5) No cultivation, no fertilization.

On the control plots, stumps, soil and competing vegetation were undisturbed. In the cultivated plots, the plots were disked three times each season for 3 years after planting and in the fourth and fifth seasons, the plots were mowed. On those plots which were fertilized, fertilizer was broadcast and disked into the soil at the beginning of the second season. All plots were sprayed three times with a Bordeaux mixture and DDT in both the second and third seasons. Although 14 years have elapsed since the single fertilization treatment, the high fertilization plots now still show increased growth rates when compared to the non-fertilized plots.

In an unpublished study in this same fertilization study area, John Menge demonstrated increased mycorrhizal involvement in those plots which had been fertilized. There apparently is a relationship between a single treatment of fertilizer and mycorrhizal involvement.

To examine this aspect further, as part of the overall Gulf Coast MSS forestry investigations, a program was initiated to determine the differences in mycorrhizal sporophore counts between fertilized and unfertilized plots in selected replications. The sites initially chosen are indicated by crosshatching in Figure 9. Due to time limitations, efforts during this initial study period where concentrated on the loblolly plantings in Block IV, Plots 1 and 4. These initial studies correlate well with the observations of Menge as well as correlating extremely well with growth data within these plots as reported by Dinus and Schmidtling (1971).

As part of the ERL forestry applications program, MSS data from 1220 m. over this forest area was obtained under nearly ideal conditions during May, 1974.

As input for a classification to determine the possibility of the subtle difference of signature which might result from the field observed differences of mycorrhizal involvement, the signatures from the pines in each of the two loblolly plots were used to denote this difference. Plot 1 represented a lower incidence of involvement while Plot 4 represented the higher.

The classification shows a mycorrhizal separation and the areas classified as having a high mycorrhizal involvement within Plot 4, correlate with field data from this plot which demonstrates that the areas classified as having a high involvement, were those areas which produced the highest mycorrhizal sporophore counts. The classification results of this study are shown in Figures 10 and 11.

In this paper, the author has demonstrated several techniques one can employ whereby remotely sensed data from various plant associations can be used to obtain information and classification from these plant communities which relate to other aspects of the environment. This inferential approach adds a new dimension to the information obtainable through remote sensing.

REFERENCES

Braun, E. Lucy (1950) "Deciduous Forests of Eastern North America," XIV. 596 pp. The Blakeston Co., Philadelphia, Pa.

Cibula, William G. (1972) "Application of Remotely Sensed Multispectral Data to Automated Analysis of Marshland Vegetation. Inference to the Location of Breeding Habitats of the Salt Marsh Mosquito (Aedes sollicitans)," Earth Resources Laboratory Report 020, Lyndon B. Johnson Space Center, Tx.

Czabator, Felix J. (1971), "Fusiform Rust of Southern Pines - A Critical Review," USDA Forest Service Research Paper SO-65, Southern Forest Experiment Station, Forest Service, USDA.

Fowells, H.A. (1965), "Silvics of Forest Trees of the United States." Agriculture Handbook # 271, USDA, USFS, Washington, D.C.

Dinus, R. J. and R.C. Schmidtling (1971), "Fusiform Rust in Loblolly and Slash Pines after Cultivation and Fertilization," USDA Forest Research Paper #SO-68, USDA, Washington, D.C.

Hacskaylo, Edward (1972), "Mycorrhiza: The Ultimate in Reciprocal Parasitism," Bioscience 22(10:577-582).

Vozzo, (1971) "Field Innoculations with Mycorrhizal Fungi," Mycorrhizae, Proceedings of the First North American Conference on Mycorrhizae edited by G.E. Hacskaylo, U.S. Government Printing Office, Washington, D.C.

Weber, F. P. and F.C. Polcyn (1972) "Remote Sensing to Detect Stress in Forests," Photogrammetric Engineering, Feb 1972:163-175.

TABLE I. SOME APPLICATIONS OF VEGETATIONAL CLASSIFICATION

(1) MAPPING OF SPECIATION AND SPECIES ASSOCIATIONS.

a) Marsh vegetation inventory and ecological studies.

b) Forest inventory

I) speciation

II) percentage cover or crown closure

c) Agricultural crop acreage inventory

(2) INFERENTIAL CLASSIFICATIONS FROM SPECIES ASSOCIATION CLASSIFICATIONS.

a) Marsh mosquito breeding sites and salinity regimes

b) Environmental parameters xeric vs. mesophytic sites

c) Fusiform risk zones as determined by oak-pine distribution

(3) RECOGNITION OF STRESS AND STRESS RELATED PARAMETERS.

a) Disease, e.g. fusiform rust or bark beetle infestation

b) Mycorrhizal sufficiency or insufficiency

c) Temporary water stress

TABLE II. COMPARISON OF CALCULATED PERCENTAGES OF SIX CLASSES FOUND IN TISHOMINGO STATE PARK AS DERIVED BY PHOTO INTERPRETATION AND SEVERAL MCS CLASSIFICATIONS

[Details in Text]

PERCENTAGE OF CLASSIFIABLE MATERIALS

Interpretation	Rye-Fescue	Pasture	Other Agric.	Pine	Broadleaf Hardwoods	Water	Unclass.	Totals
Photo Interpretation of RC-8 IR	0.02	0.6	0.78	46.2	42.5	5.6	4.3	100.0
Class. I	2.3	0.2	10.62	14.5	53.6	0.7	18.08	100.0
Class. II	2.2	0.5	8.0	20.0	43.2	4.9	21.2	100.0

LOCATION OF TISHOMINGO STATE PARK

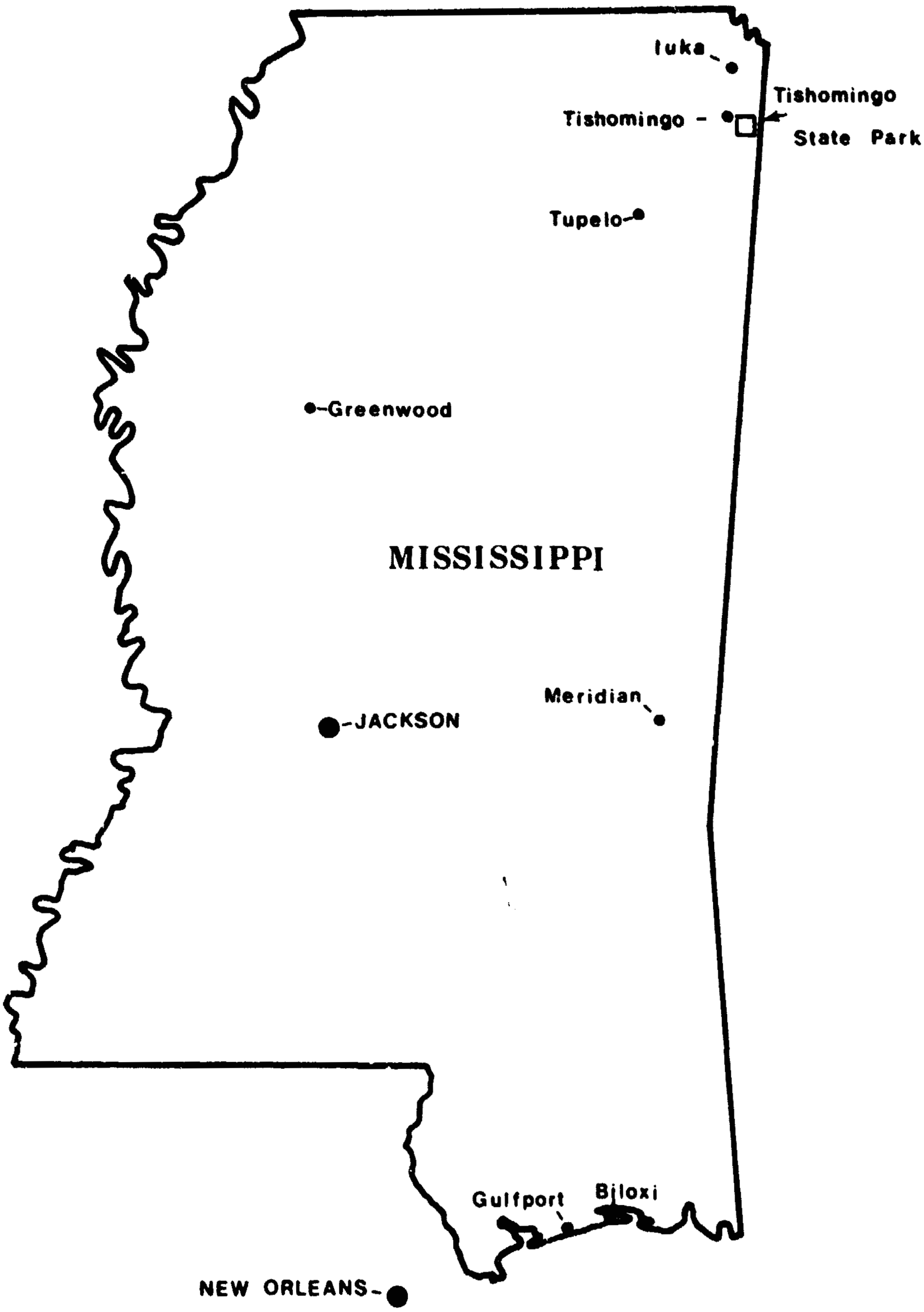
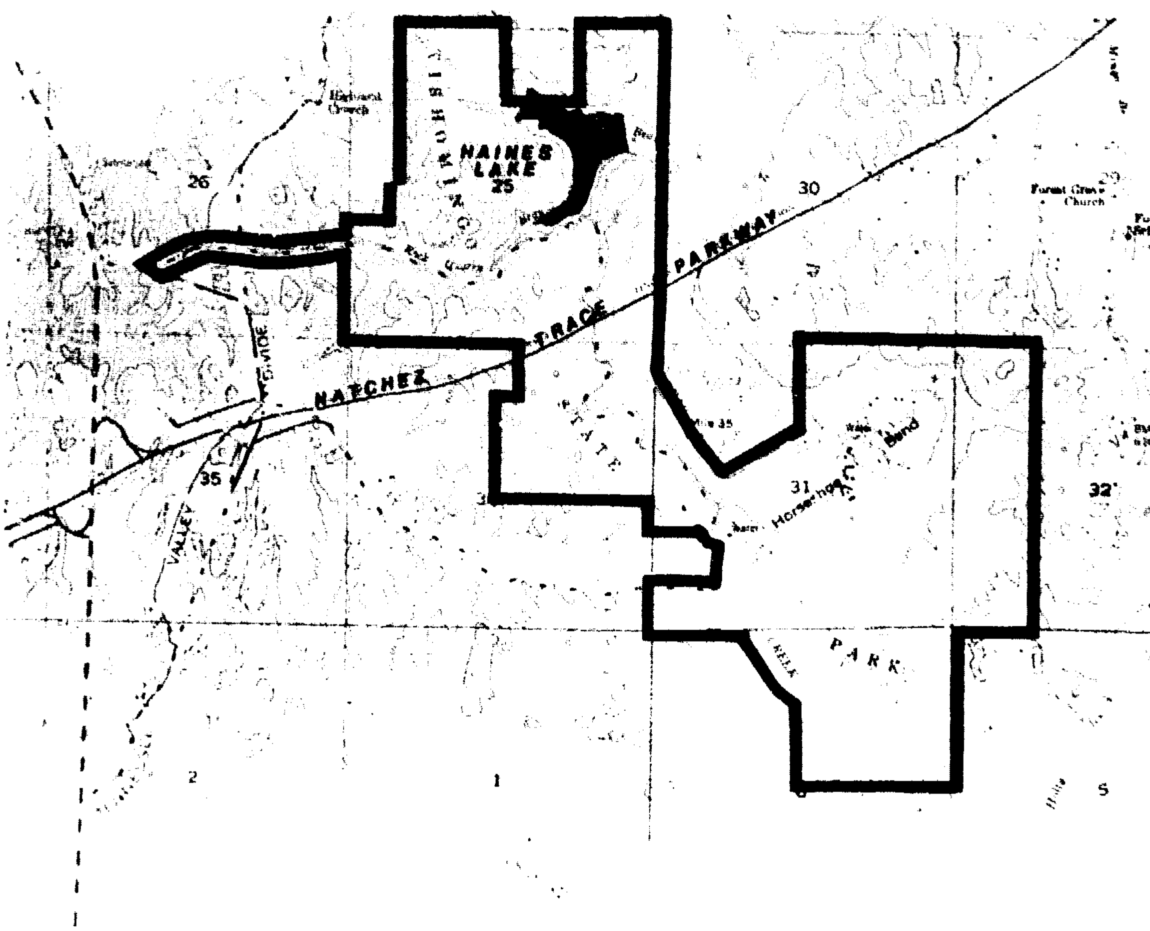


Figure 1



TISHOMINGO STATE PARK

Figure 2

Figure 3. Portion of an RC-8 color infrared photograph taken simultaneously with acquisition of MSS data.

Figure 4.- Preliminary classification of major forest types found in Tishomingo State Park, Mississippi. Red = pine; Green = Broadleaf deciduous; Magenta = Agriculture and some grasslands; Cyan = Rye/ fescue; Blue = Water; White = unclassified.

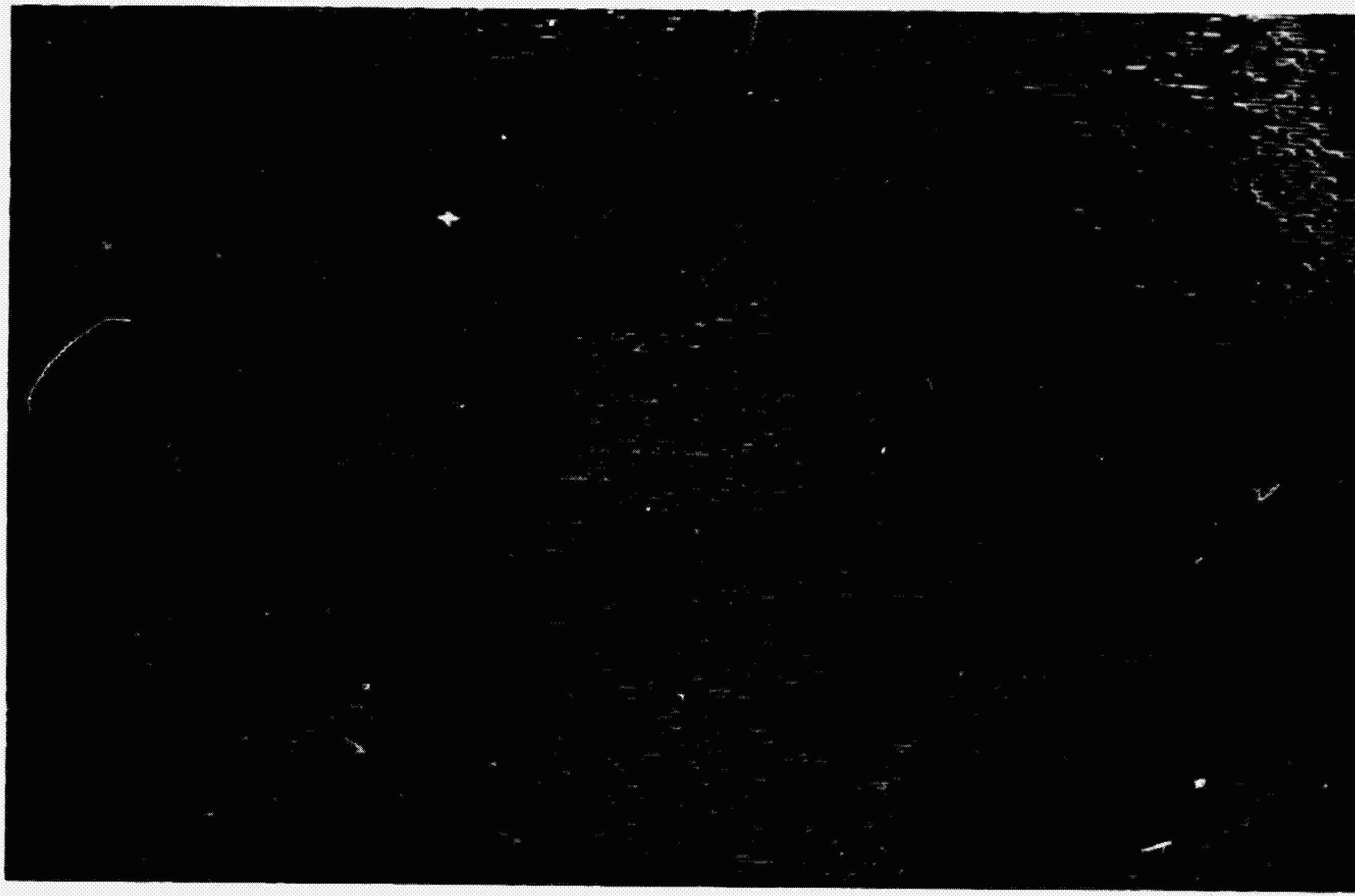
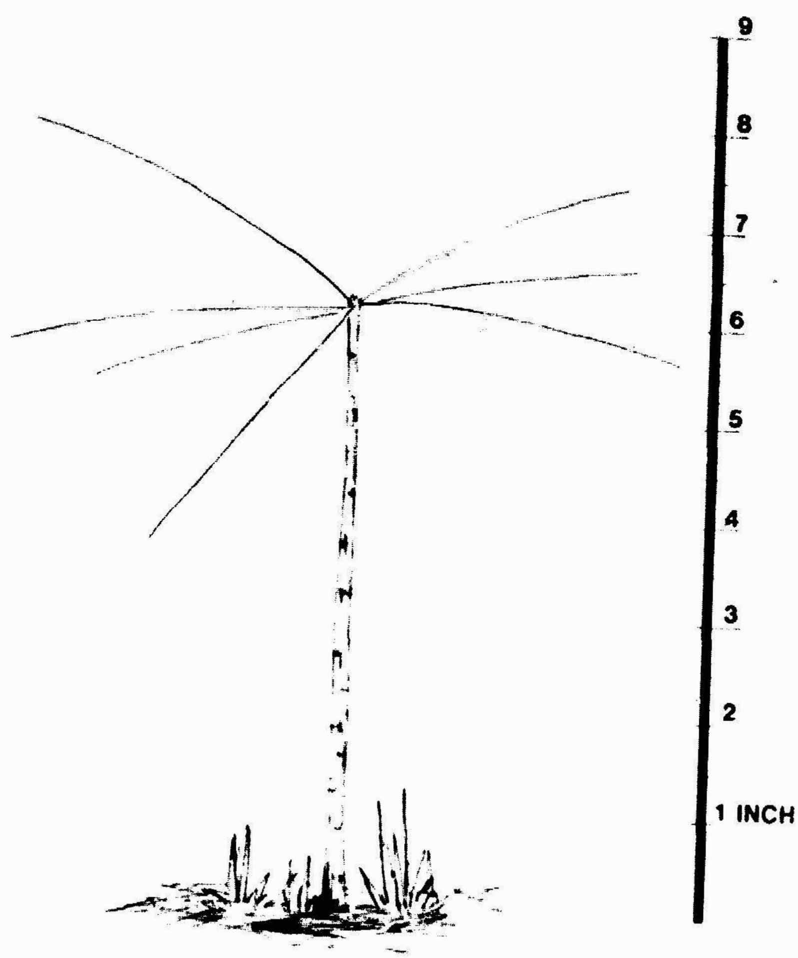
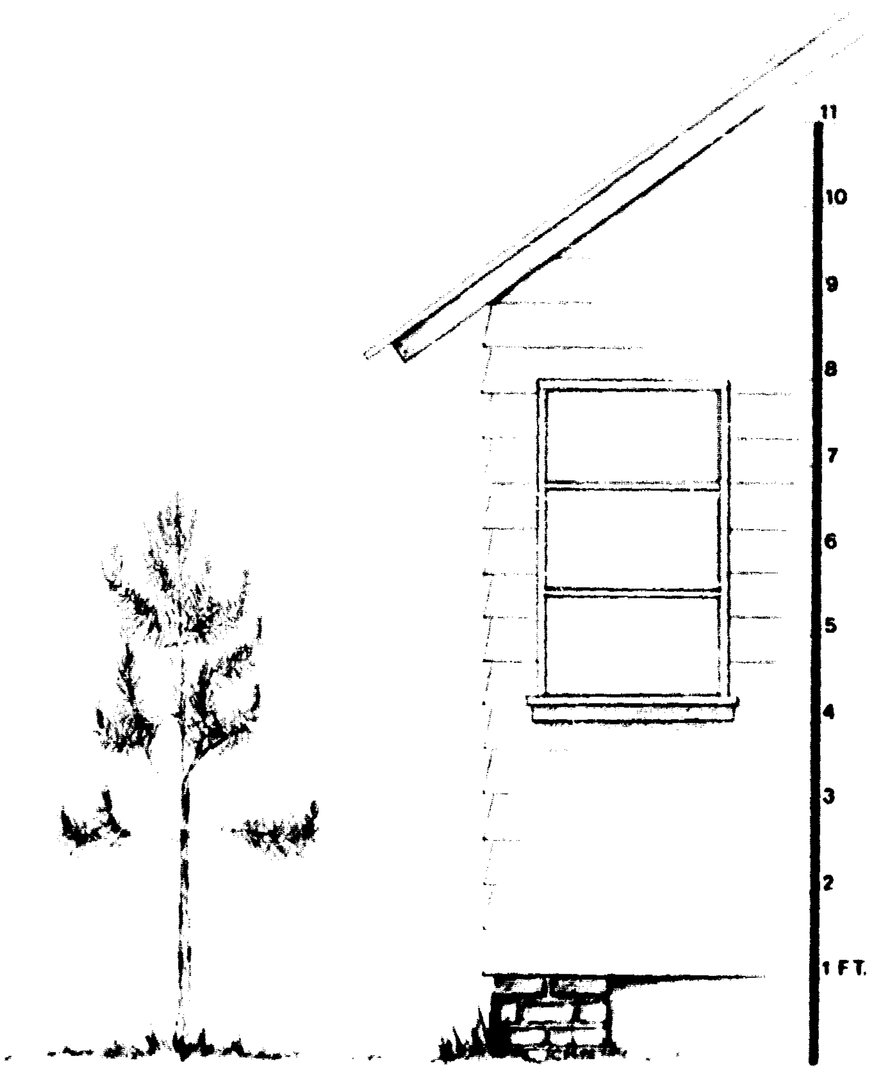


Figure 5.- Preliminary classification of major forest types found adjacent to and in the Fertilization Plot Study Area, Harrison Experimental Forest, De Soto National Forest, Mississippi. Yellow = pine; cyan = Sweetbay, Green = dogwood; orange = oak/black cherry; Gray = unclassified.



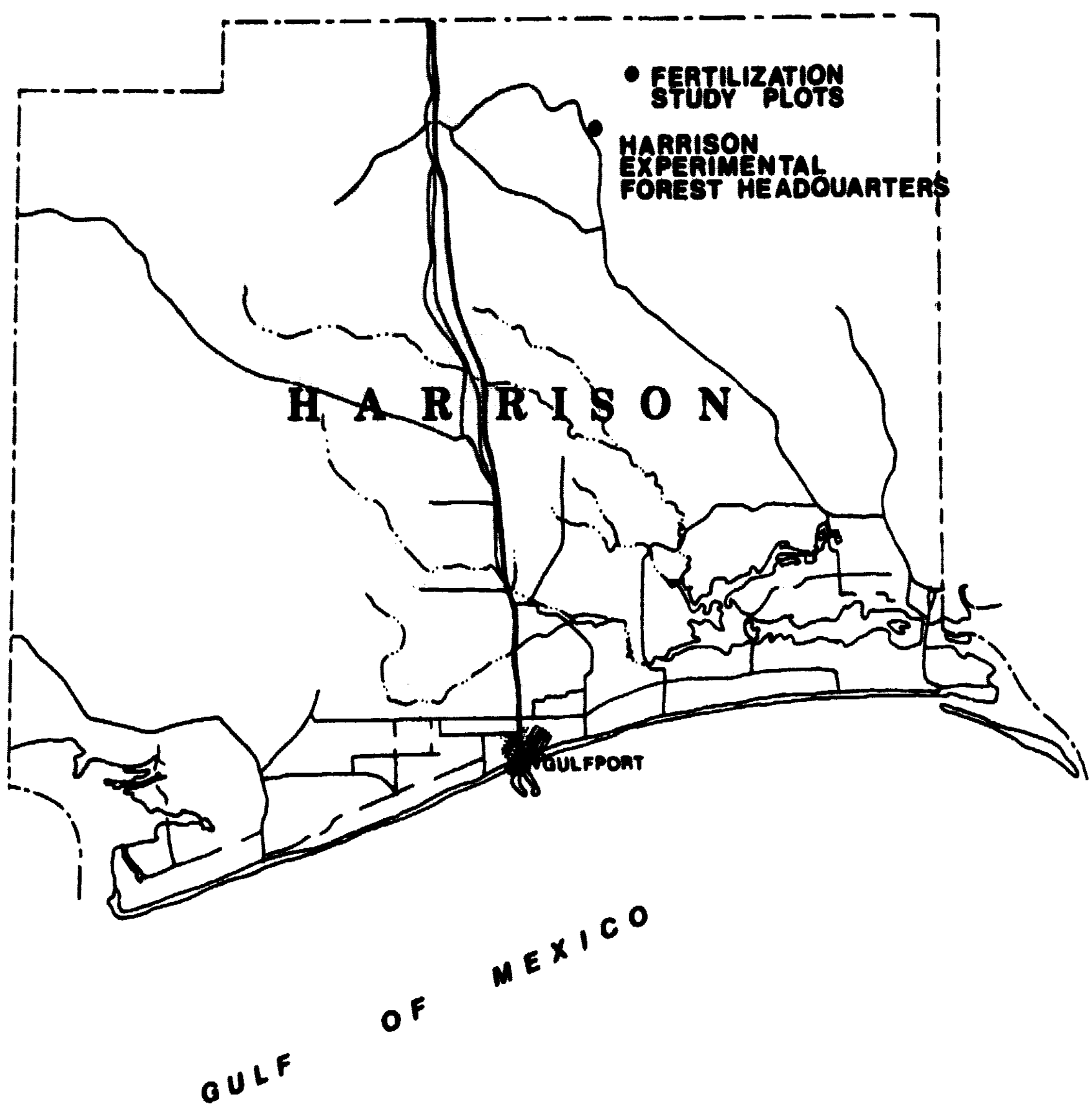
UNINOCULATED SLASH PINE SEEDLING 5 YEARS OLD

Figure 6



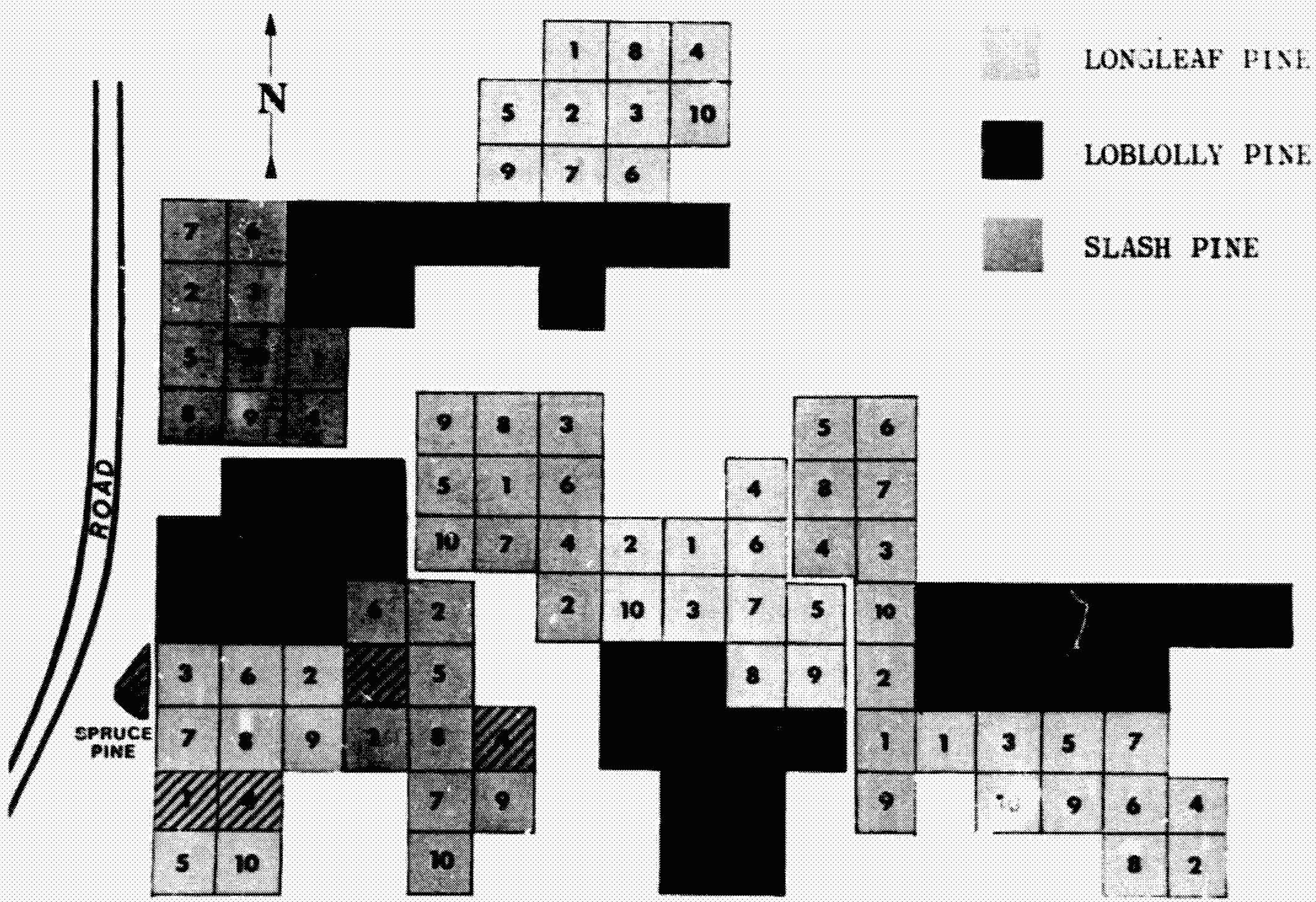
FIVE-YEAR-OLD SLASH PINE SEEDLING INOCULATED AT AGE 2

Figure 7



Harrison Experimental Forest

Figure 8



FERTILIZATION STUDY AREA

HARRISON EXPERIMENTAL FOREST

Figure 9

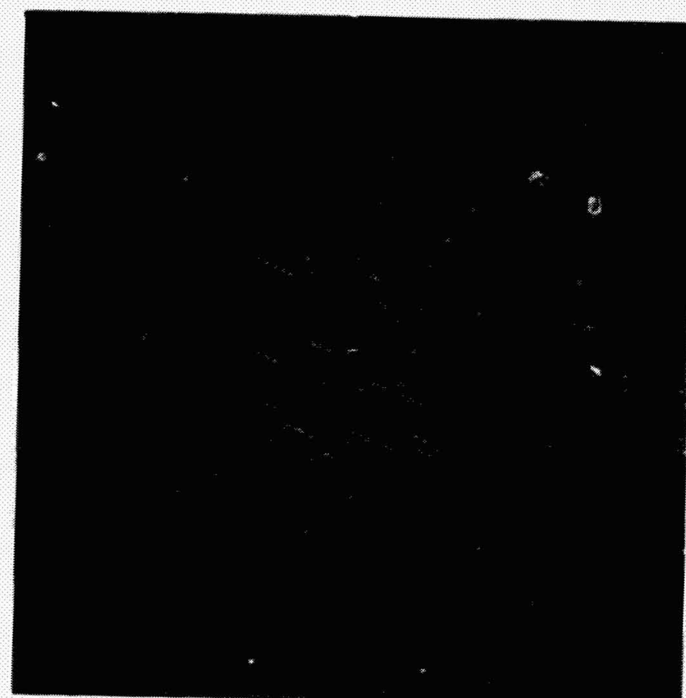


Figure 10.- Loblolly Pine, Plot 1, Block 4, low mycorrhizal involvement. Compare this figure with figure 11.

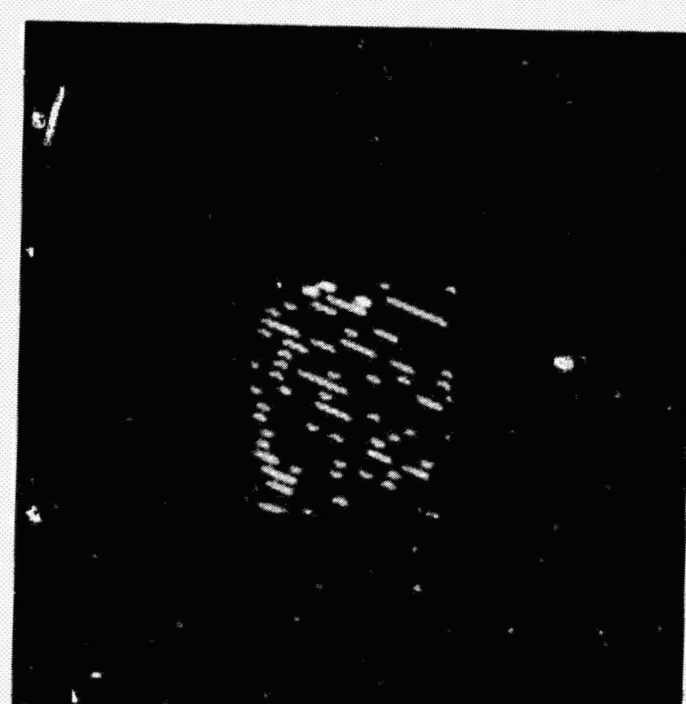


Figure 11.- Loblolly Pine, Block 4, high mycorrhizal involvement. Compare this classification with figure 10, where this same species of pine exists with a lesser degree of mycorrhizal involvement. These two figures demonstrate that the same species of pine exhibit a difference in spectral signature which can be related to the degree of mycorrhizal involvement.

A-15

THE USE OF SKYLAB DATA TO STUDY THE EARLY DETECTION OF INSECT INFESTATIONS AND DENSITY AND DISTRIBUTION OF HOST PLANTS

By W. G. Hart, S. J. Ingle, M. R. Davis
USDA, Agricultural Research Service, Southern Region
Citrus Insects Research, Weslaco, Texas

N76-17483

ABSTRACT

A study of the detection of insect infestations and the density and distribution of host plants was undertaken using Skylab data, aerial photography and ground truth simultaneously. Additional ground truth and aerial photography was acquired between Skylab passes.

For the evaluation of S-190B data, two 100 square-mile areas within the task site were selected. Area 1, of high density citrus, was located northwest of Mission, Texas. Area 2, 20 miles north of Weslaco, Texas, contained different varieties of citrus, winter vegetables, sugarcane, irrigated pastures and brush-covered land. Skylab S-190A data was also evaluated for similar information over the entire Lower Rio Grande Valley and adjacent areas of Mexico.

Aerial photographs were obtained with an aerial camera having a 304.8 mm focal length lens and a 228.6 x 228.6 mm format with false color infrared, 2443 film and with a multispectral camera using aerial black and white infrared film, type 2424.

S-190A data was recorded May 30, 1973 on 70 mm film. The highest resolution was obtained with the conventional color (SO-356) and black and white film (SO-022). A color composite picture of S-190A data using a multispectral viewer in the red, blue, green and infrared channels showed patterns of vegetation on both sides of the Rio Grande River clearly delineating the possible avenues of entry of pest insects from Mexico into the United States or from the United States into Mexico. The maximum resolution obtained with this film was approximately 150 feet.

Earth Terrain Camera imagery (S-190B) was received during the month of April, 1974. The highest resolution of approximately 27 feet was obtained with conventional color (SO-242) and black and white (EK-3414) film. The resolution of the color infrared film (SO-131) was approximately 50 feet. The conventional color film was exposed on December 5, 1973. The color infrared film was exposed on January 28, 1974.

On December 21, 1973 freezing conditions caused severe damage in some crops and eliminated some of the vegetation that normally would have been visible on the color infrared film. The identification of crops being grown at this time was obtained through simultaneous comparison of the conventional color and color IR film. With color IR film, citrus appears as a very dark red color separating it from brush and sugarcane which contained no visible red color due to damage from freezing temperatures. With the conventional color film which was exposed before the freeze, sugarcane could easily be separated from brush and citrus, but in some instances citrus could not be readily separated from brush except where the geometric shape and pattern of the field was a determining factor.

Other vegetation that could be identified with Skylab color IR film was winter vegetables, alfalfa, irrigated pastures, unimproved pastures and different densities of citrus plantings. Insect infestations in citrus were at low levels during the Skylab pass. However, with the resolution capability of color infrared film and its sensitivity to infrared reflectance, it is evident that heavy infestations of

PRECEDING PAGE BLANK NOT FILMED

honeydew producing insects, such as Coccus hesperidum L., Planococcus citri (Risso) or Aleurocanthus woglumi Ashby, in citrus would have been detectable. Dark soil patterns within a grove could adversely affect the detection of insect infestations since the overall reflectance would be reduced and the contrast between dark areas would be less detectable.

INTRODUCTION

Aerial photography has been demonstrated to be an effective tool in research and the practical applications of agriculture. Hart and Myers (1968) using aerial color infrared film were able to detect light to heavy infestations of brown soft scale, Coccus hesperidum L. on citrus. This work was accomplished with color infrared film at a photographic scale of 1:10,000. In 1973 Hart et al. demonstrated that the same technique could be used to detect citrus blackfly, Aleurocanthus woglumi Ashby, infestations in citrus groves. An aerial photographic survey method was developed from these studies that provided a rapid and effective method of detecting these problem areas, thus significantly reducing survey time and expense for this serious citrus pest.

Hart et al., in 1971, were able to identify citrus mealybug infestations using aerial color infrared film. The identification of brown soft scale, citrus mealybug and citrus blackfly infestations on citrus foliage is accomplished by detecting the sooty-mold fungus, Capnodium citri Berk, which grows on honeydew, an end product of metabolism of these insects. The patterns in which the sooty-mold develops on the foliage provides an effective means for specifically identifying infestations of each of these three pests of citrus.

Aerial photography, using color infrared film provided detection of three insects, one mite and three diseases on pecans and peaches in South Georgia (J. A. Payne, et al. 1971).

Ants can also be easily detected with aerial photography as a result of their characteristic mounds. In 1971 studies by Hart demonstrated that mounds of imported fire ants Solenopsis invicta (Buren) could be detected with aerial infrared color photography and that an inexpensive technique for aerial surveys could be established. Later studies by Green et al. (1975) provided in depth information on precise altitude and effectiveness of this survey technique for imported fire ants. Other ant mounds that can be detected are those produced by the harvester ant, Pogonomyrmex barbatus (F. Smith) and Texas leaf cutting ant, Atta texana (Buckley).

These studies demonstrated that insect infestations of crop plants and pastures that are detectable by aerial photography can be divided into four categories according to the type of damage they cause: (1) honeydew producers from which sooty-mold deposits develop on foliage, (2) those that distort geometric patterns of plants, (3) those that cause color changes in foliage and (4) those that produce identifiable structures (i.e. ant mounds).

The ability to rapidly identify the density and distribution of host plants of various pests can provide a major input into large scale eradication programs of established pests, containment or control programs of newly introduced pests, and in studies of population dynamics. Usually the most damaging situation that can occur with an insect pest is the introduction of a destructive species to a new area. This results because the pest insect usually arrives without any of its natural enemies

which causes the pest population to increase very rapidly, inflict severe damage to an area, and remain destructive for prolonged periods. A thorough knowledge of all vegetation in areas that are potential hosts of new introductions of insect pests is vital for the prevention, eradication, containment, or control of these pests. Adequate ground surveys of many of these areas are frequently impractical because they are extremely time consuming, costly, and in most cases not very efficient, since many of the areas of concern are inaccessible. In view of this, Hart and associates in 1973 developed techniques for determining the density and distribution of host plants of various pests using aerial photography. Since aerial photography using color infrared film proved successful in the above studies, the use of Skylab data was investigated to determine the feasibility of detecting insect infestations and avenues of entry of pests into previously uninfested areas.

Methods and Materials:

A task site was established in the Lower Rio Grande Valley from which data was gathered using ground surveys, aerial photographs and Skylab data. Within the task site, two 100 square-mile areas were selected in which data gathering was concentrated. Area 1, which contained a high density of citrus was located northwest of Mission, Texas. Area 2, located 20 miles north of Weslaco, Texas contained several varieties of citrus, winter vegetables, sugarcane, irrigated pastures, fallow land and brush-covered land. In addition to these two large plots, three one square-mile plots were selected at random from within the task site in which highly concentrated data gathering was undertaken.

The data gathered by ground survey was concerned with insect infestations, planting densities, variety differences, soil patterns, crop inventories, acreage measurements and location of canals, roadways, drain ditches, lakes and low areas.

Aerial photographic data was acquired with an aerial camera which had a 304.8 mm focal length lens and a 228.6 x 228.6 mm format. Film used in the camera was color infrared film (2443) with a filter pack containing a Wratten 12 and 40 cc blue filter. Aerial photographs were taken at altitudes of 609, 1524 and 3048 meters, above ground level providing a scale of 1:2000, 1:5000 and 1:10,000, respectively. A single engine aircraft containing a 450 mm diameter camera port on the floor to facilitate vertical photography was used for a photographic platform. The film was processed at the Citrus Insects Laboratory, Weslaco, Texas. Photography obtained was viewed on light tables with or without magnification and compared with ground truth and Skylab data.

A multispectral camera with aerial black and white infrared film (2424) was also used for gathering aerial data. This camera contains four 150 mm focal length lenses. Each frame recorded four images of the same area simultaneously, each with a format of 57 mm x 103 mm. One image was photographed in the green wavelength band, one in the blue band and one in the near infrared to 900 nanometers. This data was viewed with a multispectral viewer which can be used to combine all four channels, producing a color composite, or to view any of the wavelength bands separately or in combination.

Skylab data was received from S-190A and S-190B cameras. The S-190A camera, a multispectral photographic camera system consists of an array of six 70 mm cameras, each equipped with f/2.8 lenses having a focal length of 152.4 mm which provided approximately 25,600 sq. kilometers of ground cover per frame. Each camera was designated as a station and was equipped with different film and filter combinations. Camera stations one and two contained black and white infrared film (2424) and a

CC[1/] filter (0.7-0.8 micrometer) and a DD[1/] filter (0.8-0.9 micrometer), respectively. Station three contained EE[1/] filter (0.5-0.88) and color infrared film (2443). Station four was equipped with a FF[1/] filter (0.4-0.7 micrometer) and hi-resolution color film (SO-356). Stations five and six were equipped with black and white film (SO-022) and contained a BB[1/] filter (0.6-0.7 micrometer) and an AA[1/] (0.5-0.6 micrometer), respectively.

The Earth Terrain Camera, S-190B, utilized 127 mm film and was equipped with an F/4 lens with a focal length of 457.2 mm providing ground coverage of approximately 11,881 sq. kilometers. Earth Terrain Camera imagery was exposed Dec. 5, 1973 and Jan. 28, 1974 and was received April 1974. This imagery consisted of conventional color film (SO-242) and high-resolution color infrared film (SO-131).

S-190A data was received during the month of August, 1973. This film was exposed May 30, 1973 and covered a major portion of the task site. A large area south of the task site, in Mexico, was also included in the coverage. The S-190A data was evaluated by comparing it visually with aerial photography and ground data. The black and white multispectral Skylab photography was observed in the multispectral viewer, producing a color composite which was compared with the other data.

When the Skylab 190B film was received, enlarged 35 mm transparencies were made from the original scale of 1:1,000,000 to a scale of 1:63,000. This was then projected to provide a scale of 1:10,000. Using this scale, two agricultural photointerpreters analyzed all items in each test site on each film type. After analyzing each film independently a comparison study was made of the color IR and conventional color films. Using this technique color, density, and physical features provided information necessary for correct identification of the composition of the agricultural scene. The interpretation was aided by the fact that the conventional color film was exposed before a freeze and the color infrared was exposed after the freeze. Fig. 1 demonstrates one of the test sites and the sources from which the data was acquired.

In order to determine the accuracy of the interpretation of various features within the areas, a study was conducted using S-190B color infrared and conventional color film. Within the 100 square mile test area, three one square mile test sites were randomly selected. Ground surveys were conducted to obtain ground truth which was used as a basis for determining accuracy. Aerial surveys using color infrared photography of the three sites were also conducted. All of this data was obtained plus or minus 24 hours of the Skylab pass over the task site.

The Skylab 190B was analyzed to identify various crops in the test site with both color infrared and conventional color film and to evaluate the influence of freezing temperatures and other environmental factors on sugarcane, cabbage, alfalfa and soil reflectance patterns. Since it was anticipated that the planting density of citrus trees would effect the gross reflectance from the crop and thus influence the accuracy of detection of problems, a study was also made on the effect of tree spacing on reflectance.

In order to demonstrate the ability to quantify differences between brushland, sugarcane and citrus, a density study of the various areas was conducted on conventional color S-190B film. Using a 1:63,000 scale transparency, six randomly selected density readings on each film type were made with a transmission densitometer that has a 1-mm aperture.

[1/] AA, BB, CC, DD, EE and FF are NASA designations for filters providing the band widths indicated.

Since color infrared photographic data was obtained using different types of color infrared film and exposed from different altitudes above the subject being photographed, a comparison test of resolution was undertaken to determine the effects of the different types of film and altitudes on resolution.

The test plot used for this comparison was located in area No. 2 and contained 640 acres. The plot contained crops, fallow land, roads and canals from which accurate measurements on the ground were taken.

Skylab photography, S-190A and S-190B was enlarged photographically to its maximum useable scale which was 1:200,000 for S-190A and 1:30,000 for S-190B. S-190A used EK-2443 color infrared film and S-190B used SO-131, a high resolution color infrared film.

Aerial photography with color infrared film (2443) exposed at a scale of 1:10,000 over the test plot was adjusted to a scale of 1:20,000 to compensate for the smaller adjusted scale of Skylab data and thus make the comparisons more equitable.

Objects measured on the ground were located on the aerial and Skylab data and comparative measurements were taken from each photograph. Only areas of high contrast were used so that the maximum resolution could be obtained.

Results:

The S-190A data provided significant information on areas of vegetation on both sides of the Rio Grande River. On the conventional color film the physical features of the area such as drainage patterns, water courses and some soil characteristics are readily apparent (Fig. 2a). With the color infrared film (Fig. 2b) the patterns of vegetation which appear as shades of red are very clear. Despite reduced resolution much more information about the distribution of vegetation on both sides of the border is evident with the color infrared film. This photography clearly defines the possible avenues of entry of pest insects from Mexico into the United States and the United States into Mexico because of potential host distribution. The multispectral color infrared composite picture (Fig. 2c) which included the spectral region between 0.5 to 0.9 micrometers, intensified the signature of vegetated areas making it possible to see more vegetation and more accurately pinpoint possible avenues of entry of pest insects. Areas of little vegetation and subsequently less stress, are also clearly evident.

Following the freeze of December 21, 1973 sugarcane demonstrated a major change in reflectance but pastures, and annual crops showed little change. This was due to the absence of chlorophyl in the sugarcane brought about by freeze injury. In Fig. 3, the two film types (color IR and conventional color) each exhibited advantages for some problems, but when the films were viewed simultaneously, comparing each item, the accuracy of identification increased markedly. This is due in varying degrees to the two film types, to the differences in reflectance characteristics that occurred after a freeze, and to the combination of both.

With the color infrared film, annual crops, fallow land, variations in soil color and low areas were correctly identified 100% of the time. Citrus was identified with

93% accuracy. With conventional color film the accuracy of identifications of citrus dropped to 80% but when both films were compared, citrus was identified correctly in every instance.

When comparing the 2 film types the only items identified with less than 100% accuracy, as indicated in Fig. 3, were brush, homesites, missing plants within crops, and canals.

The best resolution obtained from S-190B data was 8.2 meters at areas of high contrast with conventional color film (SO-242). Resolution of color infrared film (SO-131) was 15.2 meters at areas of high contrast. In Test Area 1, which contained one hundred square miles, it was determined from ground surveys that citrus planting densities varied from 225 trees per hectare to 313 trees per hectare in several groves. This planting density was also very apparent with aerial photography using color infrared film (2443) at a scale of 1:10,000. When viewing S-190B color infrared film, the higher density planting areas appeared darker in color than the lower density plantings (Fig. 4). This was most obvious when citrus was planted on highly reflective soils.

At the time of year S-190B film was exposed, a large portion of the cultivated land in the task site was fallow land. Vegetation present at that time of the year was limited to citrus, sugarcane, winter vegetables, irrigated pastures and cover crops. Uncultivated land contained sparse vegetation of native grasses, shrubs and trees.

With S-190B color infrared film (Fig. 5a) citrus appeared as a very deep red color, separating it from brush and sugarcane which contained little or no visible red color at this time of year. On Dec. 21, 1973 the sugarcane had been subjected to freezing temperatures shortly before it was photographed leaving it devoid of any infrared reflecting chlorophyl. Brush at this time of year does not normally show up well on color infrared film due to the reduced chlorophyl content. With normal color S-190B data (Fig. 5b) sugarcane which had not been damaged by adverse temperatures when this film was exposed could easily be separated from brush and citrus, but citrus in some instances appeared very similar to brush. In some cases the geometric shape of the field could be used as a determining factor in separating the two. Brush covered areas in the test site are usually large and have irregular patterns whereas most citrus groves in the valley are smaller and more uniform in color and texture throughout.

A field of sugarcane planted on the east side of a large body of water, Delta Lake, demonstrated the moderating effect of large bodies of water on temperature extremes. The sugarcane next to the lake, which was uninjured by freezing temperatures, appeared red on S-190B color infrared film while cane at a greater distance from the lake, appeared black, demonstrating the effect of freeze injury (Fig. 6a). This was the only field that was observed to be undamaged on S-190B color infrared film following the December 21, 1974 freeze.

The most abundant winter vegetable growing at the time S-190B color infrared and conventional color film was exposed was cabbage. With CIR film cabbage appeared bright red which was easily distinguished from the dark red signature of citrus (Fig. 6b). Harvested cabbage fields appeared pink. On the S-190B conventional color transparencies mature cabbage appeared green and after harvest was light green.

Alfalfa appeared as a much brighter red color than all other vegetation growing at the time S-190B color infrared film was exposed. Alfalfa foliage usually provides complete coverage of the soil thus preventing any interference with overall IR reflectance characteristics. An alfalfa field within the first area of the task site had suffered considerable wind damage leaving areas within the field void of vegetation. This was very apparent when viewing S-190B color infrared film (Fig. 6c) because of the bright red reflectance of the undamaged alfalfa compared to the white reflectance of dry soil where the damage occurred.

Problems in sugarcane fields such as chlorotic areas are hard to detect from the ground due to dense planting. With aerial photography, these areas can be easily seen. Chlorotic areas were detected in a sugarcane field when viewing S-190B normal color film (Fig. 6d) The smallest area that could be seen was 9 meters in diameter when magnified to a scale of 1:125,000. Figure 6d is an example of a sugarcane field containing several chlorotic spots. Approximately ten acres of the 40 acre field had chlorotic damage.

Soil reflectance patterns were demonstrated to have an adverse effect on the identification of some citrus problems with data acquired from aircraft and Skylab. In the task site there were two basic patterns of soil reflectance that were consistently evident. These soils appeared either white or of varying intensities of blue. White soils are due to the soil being dry or very sandy. Dark soils in the test site were due to the high moisture content of the soils or deposits of silt that accumulate in various locations. S-190B color infrared data (Fig. 6f) demonstrates fallow land containing light soil with a dark soil pattern running through it. In a citrus grove, where the reflectance of soil blends with the reflectance of foliage, soil patterns can cause difficulty in interpretation of the data from Skylab (Fig. 6e). Dark soil patterns in a citrus grove may appear similar to insect infestations or high density of plantings.

The average diffuse transmission density (6 readings each) for brushland, sugarcane and citrus was 13.1%, 21.0% and 9.8%, respectively (Fig. 7). While there was some overlap in the readings for brushland and citrus, it is evident that the averages are significantly different and that brushland and citrus can be separated with this technique.

Using the ground data and the photographic data, resolutions were established. Aerial color infrared film provided a resolution of 46 cm., S-190A 45.7 meters and S-190B 15.2 meters (Fig. 8).

Conclusions:

Satellite data such as that obtained from Skylab S-190B offers promise for detection of some insect pests and the distribution of host plants of various insect pests. The practical applications of this technique will be dependent on maximum resolution and rapid turn around time in receipt of the data.

With comparative observations of film types and seasonal influences on reflectance characteristics, many crop varieties can be identified with Skylab S-190B data.

Vegetative patterns in border areas can be detected with Skylab S-190A and S-190B data. This information can be useful in detecting avenues of entry of pest species and areas of stress that require greater vigilance in stopping the spread of destructive species.

The influence of some environmental factors on crops that may be confused with pest injury, or related factors, can be detected and identified with Skylab S-190B data.

REFERENCES CITED

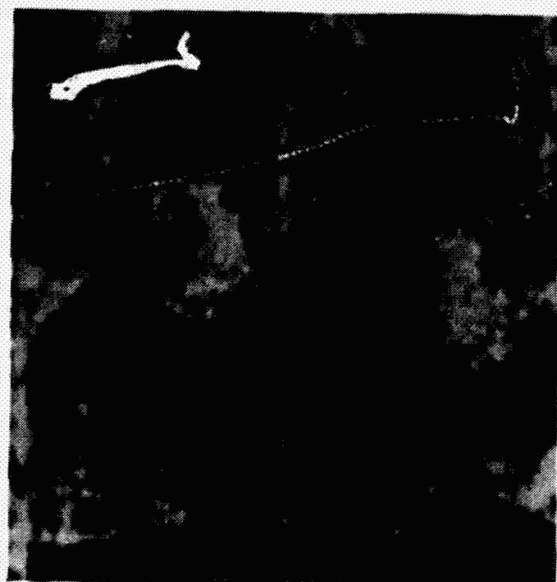
Green, L. R., J. K. Olson, W. G. Hart and M. R. Davis. 1975. Comparison of aerial color, color infrared and black and white infrared film types for detection of imported fire ant mounds. J. Econ. Entomol. In Press.

Hart, W. G. and V. I. Myers. 1968. Infrared aerial color photography for detection of brown soft scale in citrus groves. J. Econ. Entomol. 61: 617-24.

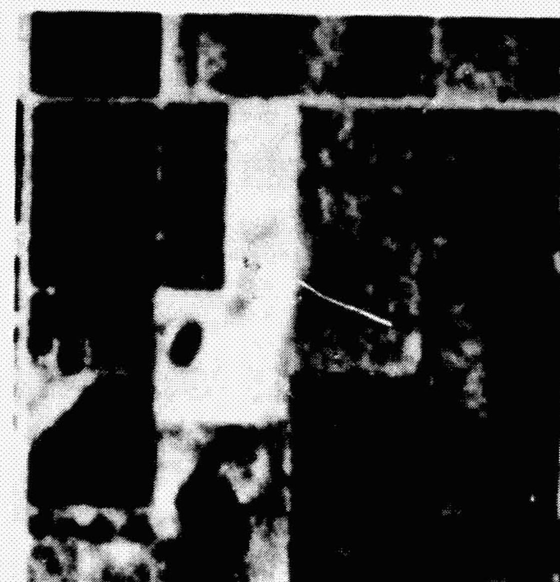
Hart, W. G., S. J. Ingle, M. R. Davis, C. Mangum, A. Higgins, and J. C. Boling. 1971. Some uses of infrared aerial color photography in entomology. Proc. of the Third Biennieal Workshop on Color Aerial Photography in the Plant Sciences, 99-113, Mar. 2-4, 1971, Gainesville, Fla.

Hart, W. G., S. J. Ingle, M. R. Davis and C. Mangum. 1973. Aerial photography with infrared color film as a method of surveying for citrus blackfly. J. Econ. Entomol. 66: 190-4.

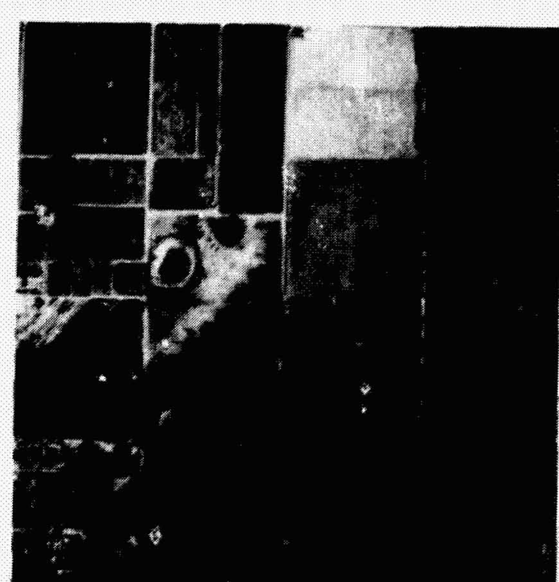
Payne, J. A., W. G. Hart, M. R. Davis, L. S. Jones, D. J. Weaver, and B. D. Horton. 1971. Detection of peach and pecan pests and diseases with color infrared aerial photography. Proc. of the Third Biennial Workshop on Color Aerial Photography in the Plant Sciences, 216-30, Mar. 2-4, 1971, Gainesville, Fla.



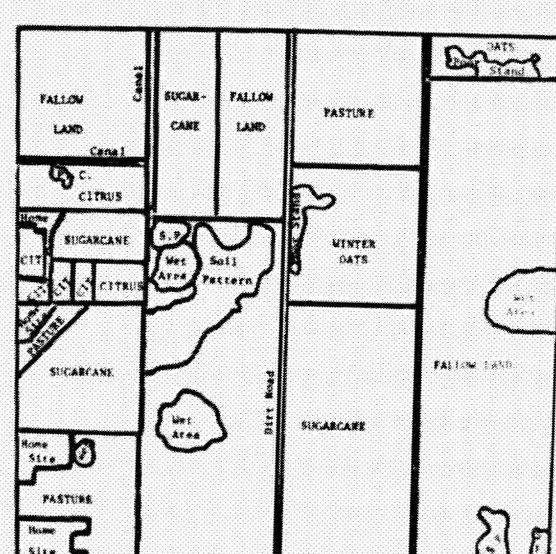
(a) Color Infrared (S-190B)



(b) Conventional Color (S-190B)

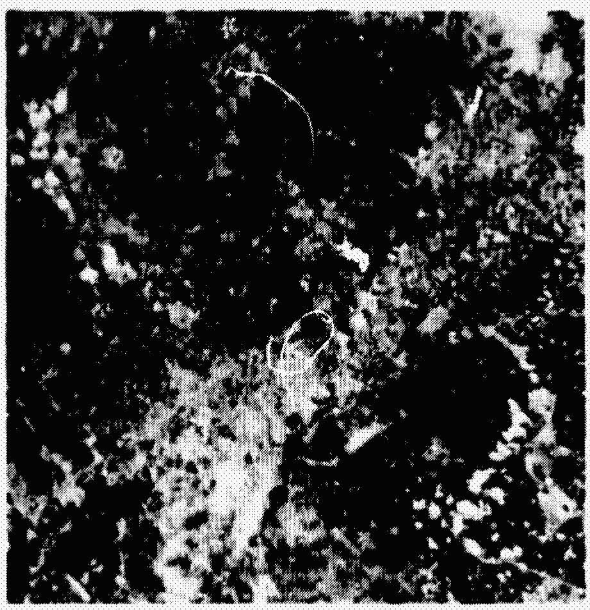


(c) Color Infrared fram Aircraft

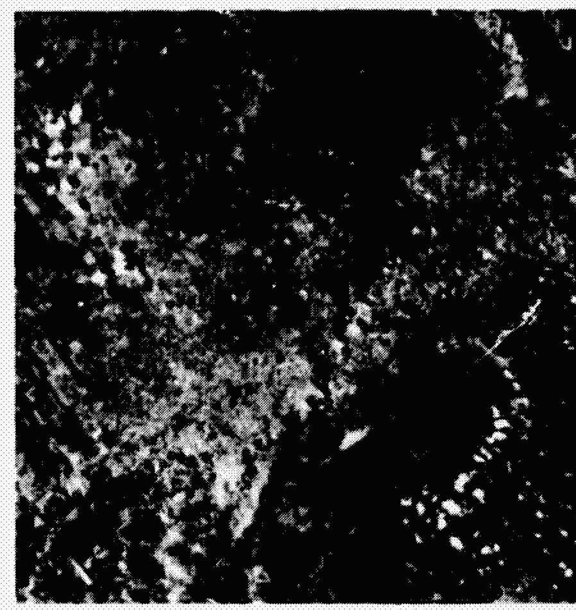


(d) Ground Truth Map

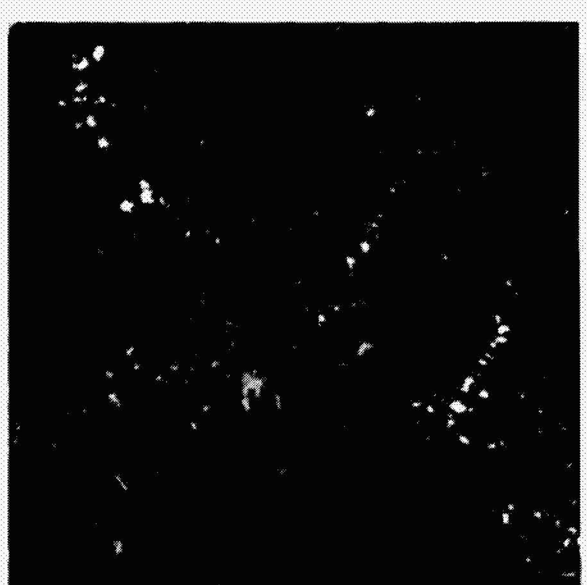
Figure 1 Comparison of data sources indicated in 1 square mile test site.



(a) Coventional Color



(b) Color Infrared

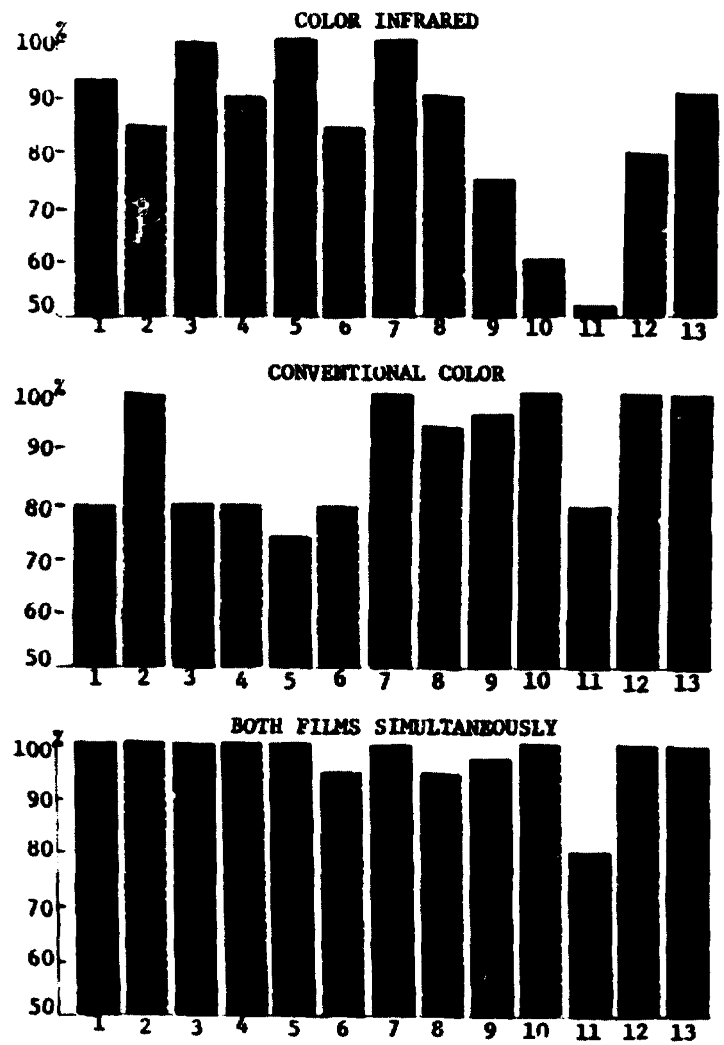


(c) Multispectral Color Infrared Composite

Figure 2 A comparison of S-190A conventional color, color infrared and black and white film. Black and white film was combined in a multispectral viewer to produce the color composite.

PHOTO INTERPRETATION ACCURACY FOR SKYLAB 190B DATA

Figure 3.



1. CITRUS (2 YRS. AND OLDER)
2. SUGARCANE
3. ANNUAL CROPS
4. PASTURES
5. FALLOW LAND
6. BRUSH
7. SOIL PATTERNS AND LOW AREAS
8. HOMESITES
9. MISSING PLANTS WITHIN CROPS
10. DRAINAGE DITCHES
11. CANALS
12. UNIMPROVED ROADS
13. HIGHWAYS

Figure 4. High and Low Density Citrus Plantings.

(a) Color Infrared

(b) Conventional Color

Figure 5. S-190B color and color infrared photographs of the 100 square mile Test Area.

(a) Sugarcane Protected from Freeze
Color Infrared

(b) Cabbage Partially Harvested
Color Infrared

(c) Wind Damage to Alfalfa
Color Infrared

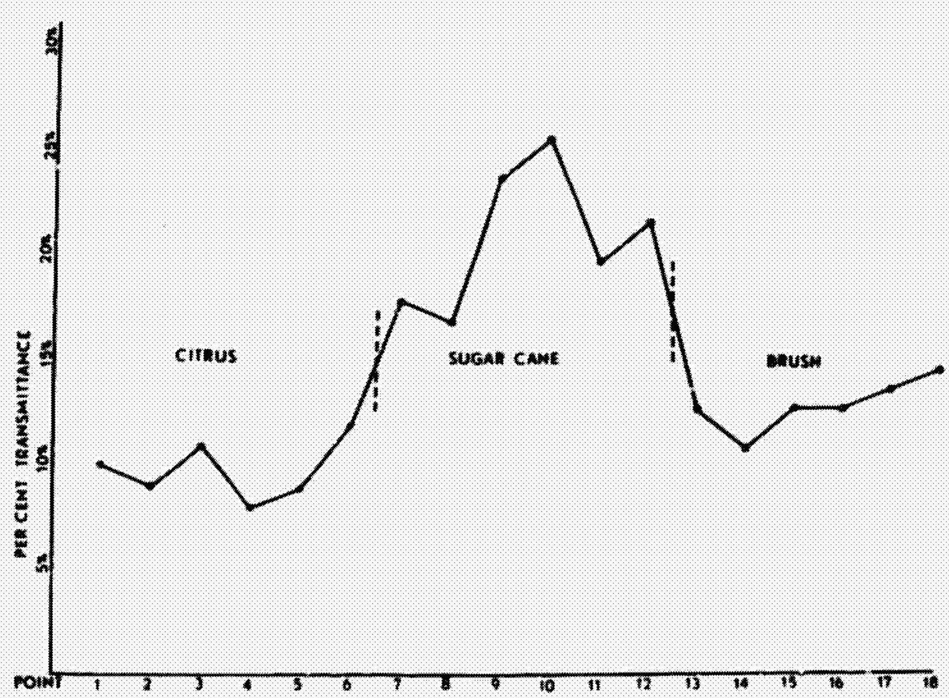
(d) Chlorotic Area in Sugarcane
Conventional Color

(e) Soil Patterns in Citrus Grove
Color Infrared

(f) Soil Patterns on Fallow Land
Color Infrared

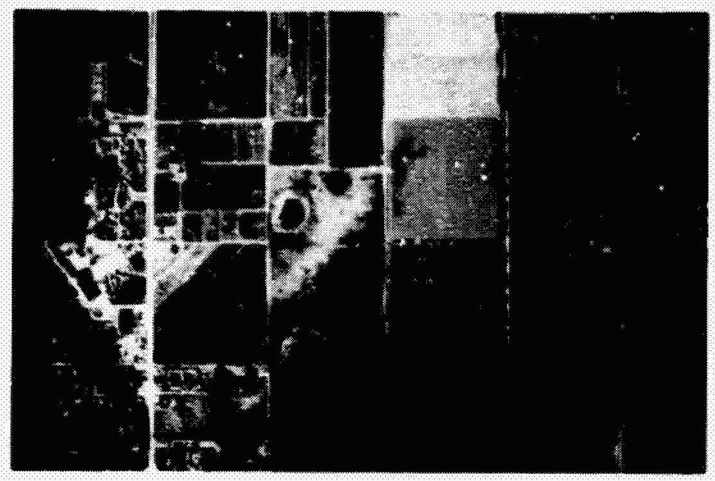
Figure 6. Selected agricultural items of interest in the 100 square mile test area.

(a) Enlarged S-190B photograph showing citrus, sugarcane, and brush

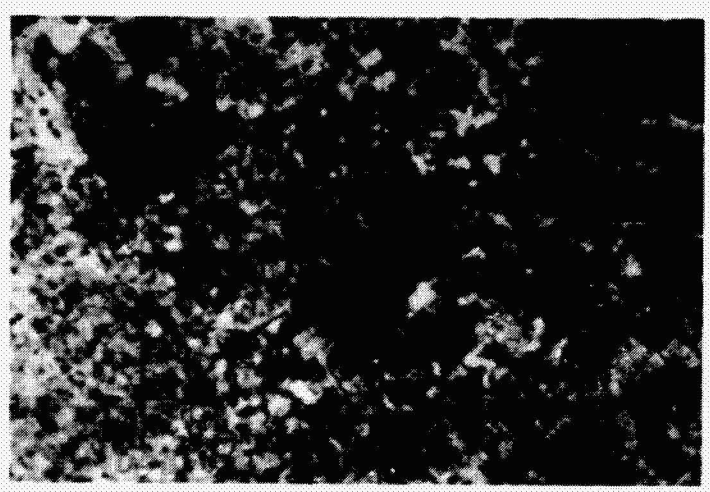


(b) Densitometer reading

Figure 7. Diffuse transmission density of citrus, sugarcane, and brush.



(a) Color Infrared Aerial Photograph



(b) S-190B Color Infrared

(c) S-190A Color Infrared

Figure 8. Comparison of Aerial, S-190B, and S-190A photography in 100 square mile test area.

A-16

AGRICULTURAL INVENTORY CAPABILITIES OF MACHINE PROCESSED LANDSAT DIGITAL DATA

By David L. Dietrich, Ronald E. Fries and Dwight D. Egbert, General Electric Company, Space Systems Organization, Beltsville, Maryland

N76-17481

ABSTRACT

Agricultural crop identification and acreage determination analysis of LANDSAT digital data was performed for two study areas. A multispectral image processing and analysis system[1] was utilized to perform the man-machine interactive analysis. The developed techniques yielded crop acreage estimate results with accuracy greater than 90% and as high as 99%. These results are encouraging evidence of agricultural inventory capabilities of machine processed LANDSAT digital data.

INTRODUCTION

There is increasing interest in both the scientific and political arenas as to the feasibility of employing satellite data for surveying world agriculture. To be effective, satellite sensors must provide a repetitive synoptic view of agricultural areas, yet maintain the capabilities of accurate crop identification and area determination. Effective agricultural survey analysis of these remotely sensed data will probably require an interactive approach combining man's insights and the machine's "number-crunching" capabilities.

The ability to extract agricultural inventory parameters from LANDSAT digital data via an interactive processing system was investigated in this study. Two areas were selected for analysis: Williams County, North Dakota and Melfort, Saskatchewan. LANDSAT imagery and detailed ground truth for a 3 x 13km (2 x 8 mile) portion of each area were provided by the U. S. Department of Agriculture (USDA).

In this study, a man-machine interactive processing system performed the analysis of LANDSAT digital data. Specifically, the system, under the guidance of an analyst, performed multispectral agricultural crop identification and spatial area determination within the study areas. The results achieved from interactive analysis were then compared to detailed ground truth.

The results are encouraging and illustrate the agricultural inventory capabilities of using interactive processing to analyze LANDSAT data. The findings indicate the potential utility of this approach to carry out large area agricultural surveys.

BACKGROUND

LANDSAT digital data of Williams County, North Dakota from July 11, 1973[2] and of Melfort, Saskatchewan from August 1, 1973[3] were furnished by

[1]The General Electric IMAGE 100 System.
[2]LANDSAT ID No. 1353-17165.
[3]LANDSAT ID No. 1374-17324.

the USDA. Accompanying the digital data were detailed ground truth crop maps of a 3 x 16km (2 x 10 mile) area within each scene. Cloud cover obscured a portion of this selected area on the Williams County LANDSAT data, forcing the study area to be reduced to 3 x 13km (2 x 8 miles). To provide consistent results, the Melfort study area was also limited to 3 x 13km.

Agricultural practices in both Williams County and Melfort are similar. Both areas are influenced by severe winters and dry summers. As a result, spring wheat is planted rather than winter wheat, and the practice of "summer fallow" is commonly employed. A summer fallow field lies idle during the growing season, and is periodically tilled to control weeds and keep the soil surface loose. This practice reduces moisture loss by soil surface evaporation and weed evapotranspiration while allowing effective catchment of the infrequent rains. This fallow ground, viewed from LANDSAT, is in high contrast with surrounding vegetation.

USDA ground truth for Williams County identified 99% of the crops within the study area as spring wheat, barley, oats, sod, grass, and fallow. Based on findings by Erb (Ref. 1), it was suspected that wheat, barley and oats would be difficult to classify separately with LANDSAT data due to close and/or overlapping spectral responses. It was also suspected that sod and grass categories, consisting of poor to fair quality permanent pastures and hay harvesting areas, may also have similar spectral responses. Consequently, the crops within the study area were analyzed in three classes: small grains (spring wheat, barley, oats); sod (sod, grass); and summer fallow.

The major crop classes in the Melfort study area were spring wheat, barley, rape and summer fallow. Again, a composite small grain category (wheat, barley) was defined for analysis. The remaining crop area was classified as either rape or fallow.

The average field size in the Williams County study area was smaller than in Melfort. Williams County field sizes ranged from 0.4 to 97 hectares (1 to 240 acres), with an average of 10 hectares (25 acres). Melfort, Saskatchewan field sizes ranged from 4 to 130 hectares (10 to 320 acres), with an average size of 22 hectares (55 acres). In both study areas, field shapes varied from small narrow fields to irregular plots to large symmetrical fields.

These areas have similarities and differences that allow for an effective comparison of results, and present an interesting challenge for using interactive machine processing to analyze LANDSAT data.

APPROACH

In order to effectively utilize the vast amount of data being generated by LANDSAT and other remote sensing systems, special purpose electronic data processing systems have been developed. One such system, an interactive multispectral image processing and analysis system, was used in this study. The basic function of the system is to extract thematic information from multichannel digital image data. This is accomplished via statistical measurement of the radiometric properties of the multichannel data as guided by an operator's interactive commands. Interactive capability to modify computer parameters and decisions is always available; changes are quickly made and evaluated. In fact, in almost all modes of operation the system responds to man at least as quickly as he can decide what to do next. The advantage of an interactive system is that it makes the most efficient use of both man and machine. The pattern recognition

capabilities and subjective judgment of the man are coupled to the "number-crunching" capabilities of the machine.

The system has four video channels, each of which is capable of storing eight-bit video image data, plus eight theme storage channels. The system uses a television compatible format of 512 x 512 picture elements (pixels) to put storage requirements at 10 million bits. For this, a solid-state memory (or rotating disc option) is used as a refresh and storage device. LANDSAT digital data can be entered directly from computer compatible tapes into the refresh memory.

In this agricultural study, the methods of interactive analysis utilized a variety of machine functions:

1. LANDSAT digital data for the Williams County study area were input at a magnification of 2X. At this scale each LANDSAT pixel (56 x 79m) is represented by a 2 x 2 pixel array on the interactive display. The scene was enlarged to facilitate visual examination of the study area. The entire screen display was 15 x 15km (Figure 1) and the study area was 3 x 13km (Figure 2).

2. The 3 x 13km study area was delineated on the color monitor with a polygon cursor (any user-defined polygon area whose position is recognized by the system during subsequent operations) so that numerical analysis results could be extracted for only the 3 x 13km study area.

3. Within the study area, small uniform portions of selected fields were designated as test and training sites. For example, portions of five known fallow fields, which were well distributed throughout the study area, were incorporated into a training site set. Portions of five other known fallow fields were selected to form the test site set. These training and test sets for all three crop categories are illustrated in Figures 3 and 4. Each set of fields represents approximately 2.5% of the total study area.

4. A first cut spectral signature including all four multispectral scanner (MSS) bands was obtained for each of the three crop classes from the defined training field sets. In training, multispectral brightness data (gray levels) within the training area are automatically measured, and their upper and lower spectral limits are used to define a single spectral cell. This spectral cell is the first cut signature of the crops within the training set. All screen pixels that lie between the bounds of this signature are then identified or alarmed on the color monitor image display.

5. The next step was to determine if each first cut crop signature truly alarmed only its own crop category. This accuracy of identification was determined by analyzing the pixels alarmed within each test field set.

   The errors of identification were presented as errors of omission and commission. For example, fallow omission and commission errors would be defined as follows:

$$\text{Omission Error (for fallow)} = 1 - \frac{\text{Number of pixels identified as fallow within the fallow test field set}}{\text{Total number of pixels defined as the fallow test field set}}$$

   % Correct Classification = (1 - Omission Error) x 100

$$\text{Commission Error (for fallow)} = \frac{\text{Number of pixels identified as fallow within the grains and sod test field sets}}{\text{Total number of pixels defined as the fallow test field set}}$$

% Commission Error = Commission Error x 100

Omission and commission errors of these first cut signatures were thus determined for each crop category: small grains, fallow and sod.

6. First cut signatures were obtained and tested at three gray level resolutions as selected on the machine, 128 levels, 64 levels and 32 levels.

7. First cut signatures include all spectral values between defined gray level limits of each training set. Further refinement of this signature was attempted automatically through a multicell signature technique. That is, the all inclusive first cut signatures (large spectral cells) were reconstructed to include only the individual pixel gray level values contained within the training area. The results of this automatic refinement technique were not encouraging; therefore, a manual interactive refinement technique was attempted.

8. The analysis objective was to obtain spectral crop signatures with characteristically low omission and commission errors. The first cut signatures were thus manipulated manually to obtain the lowest errors possible. This interactive procedure, called histogram trimming, allows the machine operator to adjust the spectral range (large cell gray level limits) of any one or all of the LANDSAT spectral bands that comprise the four channel signature. Initial trimming was made on a quantitative evaluation of the machine-displayed histograms in terms of variance, skew, etc. The new alarm created by the adjusted signature was then quantitatively tested through omission and commission error determinations.

9. Signature refinement through histogram trimming was repeated until "best results" were obtained. In this study, best results were defined as a time efficient analysis technique that produced a signature which minimized both omission and commission errors when considered simultaneously. That is, some slight trade-off between accuracy and speed of analysis was allowed.

10. The best signature for each crop class alarmed or mapped certain portions of the 3 x 13km study area. The best result classification theme maps for Williams County are shown in Figures 5 and 6. The exact number of pixels alarmed in each crop class were converted to acres for crop area comparisons with known ground truth acreage.

11. Throughout the study, MSS bands 5 and 7 appeared most sensitive in differentiating between crop classes. Therefore, classification using only these two bands of data was also attempted. The reduction in the number of spectral bands to be analyzed not only speeds analysis, but also requires less memory in the automated data processing system. These time and space savings could facilitate simultaneous multitemporal and multispectral analysis.

12. The techniques and parameters that produced the best results for Williams County were then applied to obtain signatures for the

Melfort, Saskatchewan study area. Repeating the developed classification techniques on the Melfort study area provided a check of classification and area accuracies found in Williams County. It also provided a measure of the time required to produce results rather than to investigate techniques. The Melfort study area is shown in Figure 7, and the best results classification are shown as Figure 8.

RESULTS

The results of interactive analysis of both study areas were encouraging. The developed techniques yielded acreage accuracies greater than 90% for each crop category in both the Williams County and Melfort study areas.

Williams County, North Dakota

Initial training and test statistics were the decision criteria for determining the number of spectral gray levels (32, 64 or 128 levels) that could be used most effectively on the interactive system. A gray level resolution of 32 levels was not specific enough to adequately differentiate between vegetative classes. Though initial test field percent correct classification was excellent, the commission errors were also quite high. A resolution of 128 levels introduced too many gray levels, which tended to be too restrictive and thus decreased the percent correct classification within some of the test fields. Also, visual examination of the histograms was difficult at 128 levels. At a 64 gray level resolution, initial training and testing yielded the most equitable trade-off between percent correct classification, commission error, and ease of interactive manipulation.

The primary criteria in selecting the most effective classification mode was user-interaction-efficiency coupled with accurate classification results. A first cut signature (single large cell classification) was accepted as the mode capable of providing the most rapid response to interactive commands. In addition, data operations and statistical results were more readily performed, effectively displayed and efficiently interpreted in the single cell mode.

Crop classification, based on the first cut signatures of the training fields, initially yielded high test field classification accuracies, but also yielded high commission errors. Manual refinement of the signatures, using histogram trimming, was then accomplished. Final interactive results of training and testing are represented in the first four columns of Table I. For the three categories (small grains, fallow and sod) the average percent correct classification of test fields was 93.3% with an average commission error of 3.6%.

Some tests were performed to determine if barley or oats could be accurately distinguished from wheat, or if a grass could be determined spectrally exclusive of sod. The similarity of the spectral responses within these categories, however, made more detailed stratification impractical. Therefore, all classification and acreage determinations were made using the small grains, sod or fallow categories.

The refined signatures were then applied to individual crop acreages over the entire 3 x 13km area. The number of LANDSAT pixels classified in each category was converted to hectares (1 LANDSAT pixel = 0.45 hectares) and then compared to USDA ground truth. The best results show acreage accuracies of 99.3%, 98.2% and 91.7% for small grains, fallow and sod, respectively (see Table I). Unclassified pixels amounted to 4.5% of the

study area or 181 hectares (447 acres). Overlap or conflict pixels (pixels classified as two crops) amounted to 1.8% of the study area. Most of the conflict was between the vegetative classes of small grains and sod. Fallow fields were of high enough contrast with vegetated areas to minimize conflict pixels.

Similar results were achieved when either two (MSS bands 5 and 7) or four LANDSAT spectral bands were used for classification. This result supports the findings of LANDSAT-1 investigators Landgrebe (Ref. 2) and Wiegand (Ref. 3) and others who have indicated that MSS bands 5 and 7 alone are sufficient for most agricultural applications. Band 5 (0.6 - 0.7um) is in a spectral region that is selectively absorbed by chlorophyll. Almost all energy in the spectral region of band 7 (0.8 - 1.1um) is reflected by vegetation. These two bands are therefore quite sensitive to changes in vegetation and vegetation cover, and little if any advantage is gained by using all four bands. Band 4 may actually introduce an obscuring effect due to the low contrast characteristic of this spectral range that results from atmospheric scattering. The important advantage of utilizing only bands 5 and 7 is in the reduction of interactive manipulations and the number of digital operations used throughout the classification procedure.

In summary, the techniques and parameters that were found to produce the best results were: 64 gray level resolution; and MSS bands 5 and 7, with manual histogram trimming of the first cut signature. The achieved acreage accuracies for the 3 x 13km study area all exceeded 90%. The developed techniques present an efficient, accurate way of extracting crop information from LANDSAT data using interactive processing capabilities.

Melfort, Saskatchewan

To provide a check of the procedures developed for Williams County, similar classification techniques were applied to the Melfort, Saskatchewan study area. The Melfort scene was expected to provide a reliable test of the techniques since it contained larger fields with some different crops; the crops were farther into the growing season; and the area is 565km north of Williams County, North Dakota.

Interactive classification yielded crop acreage accuracies of 98.9%, 96.0% and 98.9% for small grains, fallow and rape, respectively (see Table II). The unclassified area was 11.8% or 498 hectares (1231 acres) of the total 4229 hectares (10,460 acres) within the polygon cursor defining the 3 x 13km study area. The unclassified areas were primarily composed of roads, spaces between fields and other nonhomogeneous areas. The overlap pixels represented 4.7% or 199 hectares (492 acres) of the study area. The majority of overlap or conflict existed between the small grain and rape classes. The ground truth indicates that a few of the rape fields contained portions of wild oats and weeds. The spectral variations within these fields influenced both crop identification and crop acreage results. Similar to the Williams County site, the fallow category conflicted less than the vegetative classes.

During the training and classification of the small grain crop category within the Melfort study area, unsatisfactory results were obtained when 64 gray level resolution was used. Consequently, the system parameters were changed back to a 128 gray level resolution. The spectral properties of small grains and rape were so nearly the same that the difference of only one gray level on the 128 level scale made a significant difference in the commission errors. This points out the need to exercise caution when generalizing from the previous results obtained with only 64 gray level resolution. It also demonstrates the advantages of the man-machine interactive approach, which allows periodic human intervention in the automated

classification. The final results for the small grain category in the Melfort study area shown in Table II are for a gray level resolution of 128. All other figures in both Table I and Table II are for a 64 gray level resolution.

CONCLUSIONS

Man-machine interactive processing was used to perform agricultural crop identification and acreage determination analysis of LANDSAT digital data for two 3 x 13km study areas: Williams County, North Dakota and Melfort, Saskatchewan. Crop acreage accuracies as high as 99% were achieved by applying the techniques developed in the study. These techniques involved analysis of LANDSAT digital data MSS bands 5 and 7, at 64 gray level resolution (in some cases 128 level resolution), using first cut signatures refined through histogram trimming.

The crop identification and acreage accuracies obtained were similar in both study areas. These techniques may not be successful in all areas, but results for these particular study areas provide encouraging evidence of the utility of a man-machine interactive processing system for agricultural inventories. Unfortunately, implementation of these techniques to a larger area inventory was beyond the scope of this pilot project.

These results were obtained using only multispectral analysis. Many investigators, both at General Electric and elsewhere, concur that the accuracy of an agricultural survey will improve by combining multispectral and multitemporal input data. Crop calendar parameters could provide the inputs necessary to differentiate between crops with similar spectral characteristics, such as wheat and barley.

To summarize, the results illustrate the capability to rapidly extract accurate agricultural survey information from LANDSAT digital data via an interactive data processing system. Man-machine interactive data processing systems provide rapid and accurate crop classification through the utilization of the most efficient analysis capabilities of both man and machine.

REFERENCES

1. Erb, R. B. ERTS-1 Agricultural Analysis. Type III Final Report, LANDSAT-1 Investigation No. 1600A. August, 1974.

2. Landgrebe, D. A Study of the Utilization of ERTS-1 Data From the Wabash River Basin. Type III Final Report, LANDSAT-1 Investigation No. 1049A. October, 1974.

3. Wiegand, C. Reflectance of Vegetation, Soil and Water. Type III Final Report, LANDSAT-1 Investigation No. 1039A. November, 1974.

TABLE I. WILLIAMS COUNTY, NORTH DAKOTA TEST FIELD AND STUDY AREA RESULTS

CROP CATEGORY	TEST FIELD ANALYSES				3 X 13KM STUDY AREA		
	OMISSION		COMMISSION		COMPUTER CLASSIFIED AREA IN HECTARES (ACRES)	GROUND TRUTH AREA IN HECTARES (ACRES)	% CORRECTLY CLASSIFIED
	PIXEL NO. CORRECT	% CORRECT	PIXEL NO. INCORRECT	% ERROR			
SMALL GRAINS	212	99.5	8	3.8	1567 (3871)	1578 (3899)	99.3
FALLOW	188	87.0	9	4.2	1406 (3475)	1432 (3538)	98.2
SOD	196	93.3	6	2.9	975 (2409)	1064 (2628)	91.7

TABLE II. MELFORT, SASKATCHEWAN TEST FIELD AND STUDY AREA RESULTS

CROP CATEGORY	TEST FIELD ANALYSES				3 X 13KM STUDY AREA		
	OMISSION		COMMISSION		COMPUTER CLASSIFIED AREA IN HECTARES (ACRES)	GROUND TRUTH AREA IN HECTARES (ACRES)	% CORRECTLY CLASSIFIED
	PIXEL NO. CORRECT	% CORRECT	PIXEL NO. INCORRECT	% ERROR			
SMALL GRAINS	189	87.5	6	2.8	1656 (4094)	1675 (4140)	98.9
FALLOW	217	100.0	5	2.3	1632 (4033)	1696 (4190)	96.0
RAPE	216	99.5	6	2.8	644 (1592)	652 (1610)	98.9

Figure 1. MSS band 5 monitor image display (15km x 15km) containing Williams County study area.

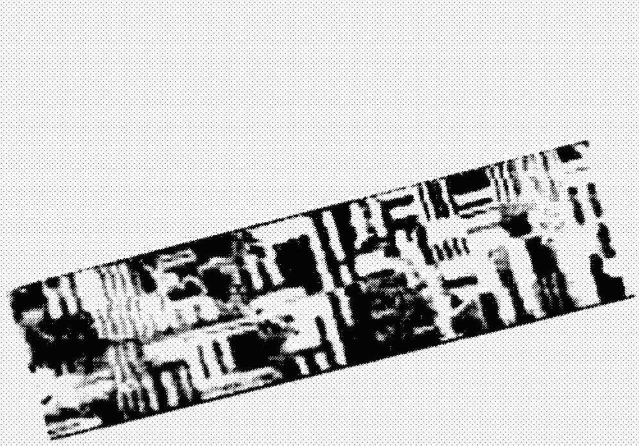


Figure 2. MSS band 7 monitor image display of 3 x 13km Williams County study area.

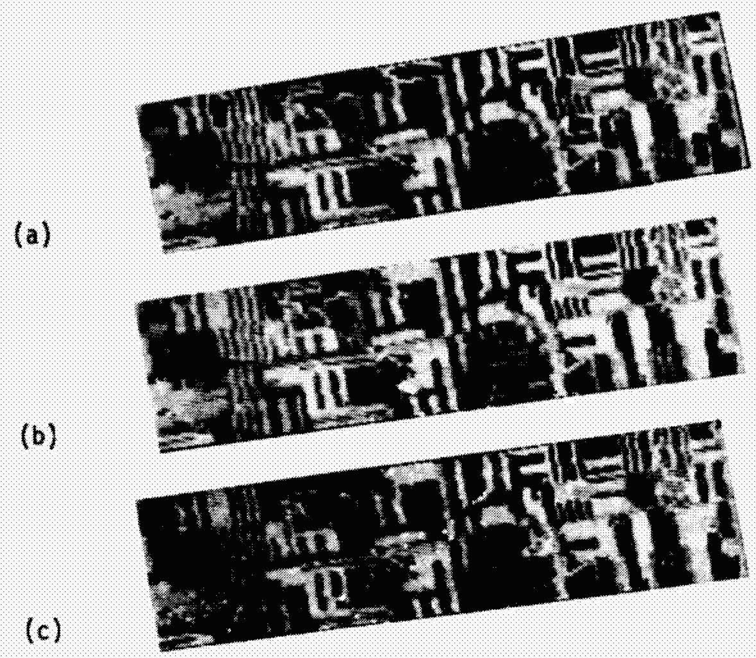


Figure 3. Williams County training fields (black) for (a) small grains, (b) fallow, and (c) sod.

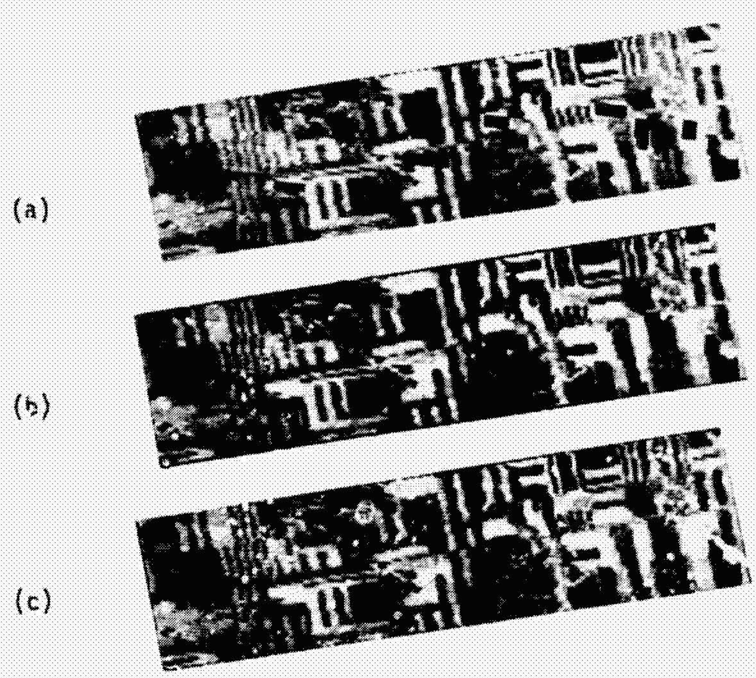


Figure 4. Williams County test fields (black) for (a) small grains, (b) fallow, and (c) sod.

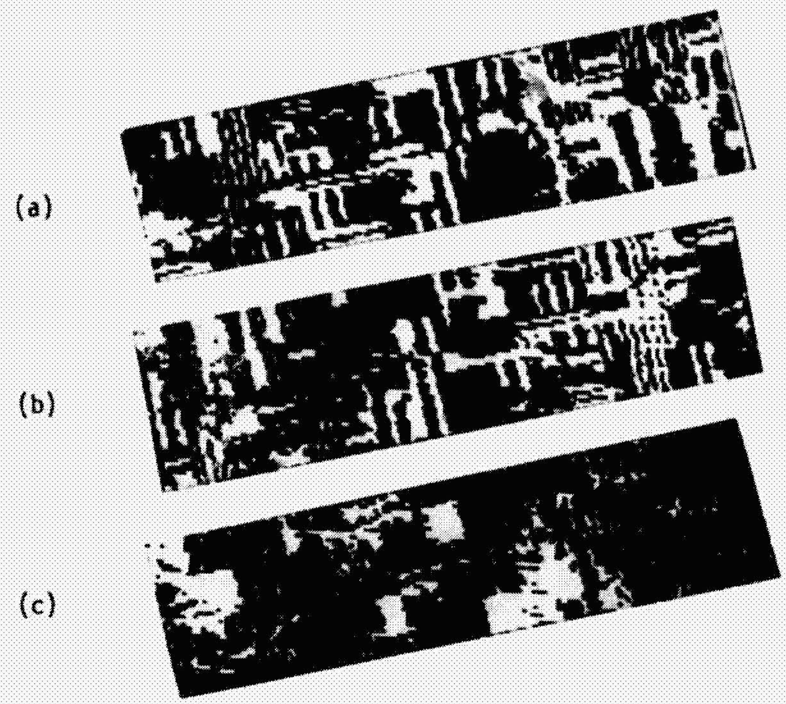


Figure 5. Classification results (white) for Williams County study area (a) small grains, (b) fallow, and (c) sod.

Figure 6. Classification results for 15km x 15km image display of Williamd County containing study area: small grains (white), fallow (medium gray), sod (dark gray), and unclassified (black).

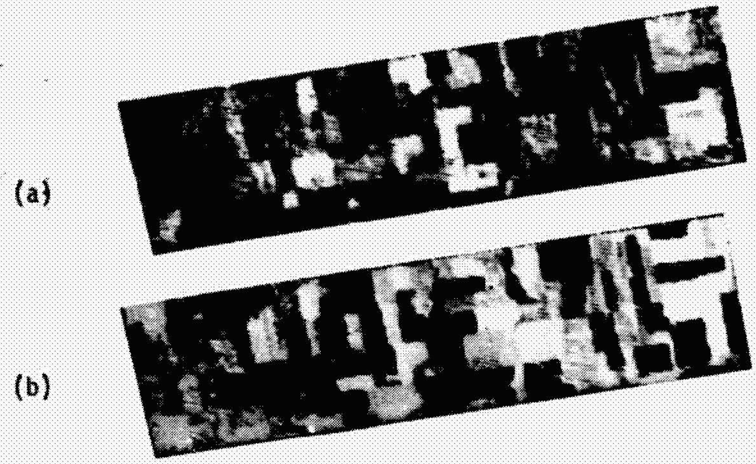


Figure 7. Monitor image display of Melfort study area: (a) MSS band 5 and (b) MSS band 7.

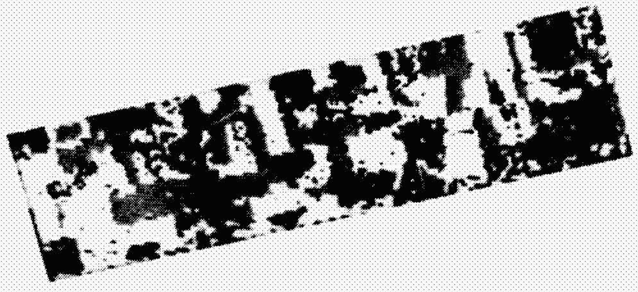


Figure 8. Classification results for Melfort study area: small grains (white), fallow (medium gray), rape (dark gray), and unclassified (black).

AGRICULTURAL APPLICATIONS OF REMOTE SENSING -A TRUE LIFE ADVENTURE-

A-17

By Earle S. Schaller, General Electric Company, Beltsville, Maryland

N76-17485

ABSTRACT

In mid-1973, General Electric undertook a study of agricultural applications of remote sensing with a major US agricultural firm. The study continued for eighteen months, and covered the areas of crop monitoring and management as well as large scale crop inventories. Pilot programs in the application of aircraft remote sensing and LANDSAT data were conducted. An operational aircraft survey program for ranch management has subsequently been implemented by the agricultural firm. LANDSAT data was successfully used to produce a ninety-seven percent accurate inventory of cotton over 4.8 million acres of California's San Joaquin Valley.

INTRODUCTION

During the eighteen month period from June 1973 to December 1974, General Electric was engaged in an agricultural remote sensing program with a major US agricultural firm. The principal purpose of this effort was to conduct a pilot program in the application of remote sensing to crop monitoring and management as well as crop inventories, and to evaluate the feasibility of a full-scale, operational program. The study was centered in California's San Joaquin Valley. The crops involved were cotton, safflower, and alfalfa.

The study divided naturally into two phases, coinciding with 1973 and 1974 crop seasons, respectively. Phase I was a learning and experimentation period, with emphasis on establishing a sound definition of the data and information requirements of this specific ranching operation. Phase II, carried out during 1974, was a period in which several operationally-oriented, pilot programs, using both aircraft and LANDSAT data, were conducted and evaluated.

PHASE I - THE LEARNING PHASE

The first season of the study was the learning phase, designed to promote a meaningful, bi-directional transfer of technology between the ranch personnel and GE project staff. GE personnel were located on-site at the firm's major ranching location and worked side-by-side with the ranch manager, agronomists, and district managers from June to October of 1973.

The Ranch

The ranching operation is one of the largest in the area with over 50,000 acres in cultivation. The principal crops covered in the study were cotton, safflower, and seed alfalfa, although wheat, barley, and milo are also grown.

The ranching operation, itself, is highly automated and capital intensive, with a minimum of labor input. This is achieved in large part by a significant economy of scale. Almost all crops are grown in full sections, each one square mile (640 acres) in area, and all of the practices and equipments used are designed for this size operation.

The San Joaquin Valley has been described as one of the most fertile regions in the world, and the careful rotation of cotton and safflower, supplemented by chemical fertilization, has resulted in maintenance and, more often, improvement of overall soil fertility.

The company continually conducts a long-range land improvement program which operates on a sliding, multi-year basis.

From May through September, the weather in the area is repetitiously rain-free, cloud-free, hot and dry. Daytime highs in July and August often range between one hundred five and one hundred twelve degrees Fahrenheit, with nighttime temperatures in the seventies. Flood irrigation is used throughout the area, with water from snow-melt in the Sierras.

Phase I Tasks

In addition to the major task, that of developing an understanding of the farming operation and practices, a number of other tasks were carried out during this Phase I period. Principal among these was the collection of ground truth data for subsequent correlation with LANDSAT imagery, later in Phase I and in Phase II. The ranch personnel, both individually and collectively, keep amazingly complete and accurate records covering literally every aspect of their operations. All of this data was made available for the current as well as past years, and this was supplemented by data collected by GE project personnel.

This ground truth activity was complemented by an experimental aircraft survey task which was conducted throughout Phase I. This experiment utilized a hand-held, 35mm camera with color-infrared film. The photos were obtained from an altitude of eight thousand feet on a nine day schedule which was timed to coincide with LANDSAT-1's eighteen day cycle. Each photo mission covered 25 full section fields selected for the purpose. In order to give this experiment an operational flavor, the photos were processed and reviewed with ranch personnel within twenty-four hours after acquisition.

Although this Phase I aircraft remote sensing experiment was simple by design, it proved highly effective in introducing the ranch personnel to the capabilities of infrared data and the advantages of repetitive aircraft coverage. The imagery did provide early detection of weeds and areas of rodent and certain insect damage. In addition, the photos permitted measurement of the areal extent of these problems.

The aerial photography also helped in identifying and assessing numerous operational ranching problems such as planter and fertilizer skips, checks missed in irrigation, and high (dry) and low (wet) areas. In several instances this resulted in modification of the particular procedure and/or equipment involved.

Variations in crop vigor were also clearly defined and, as a result, ranch personnel requested coverage over additional fields to monitor test plots and problem areas.

Throughout Phase I, LANDSAT MSS data in the form of black and white and color composite transparencies was obtained and analyzed visually. The most current imagery available was some three to four months behind the actual date and of little value for other than research and historical purposes. No operational use for this data was found. Late in Phase I, however, LANDSAT imagery which coincided with the aerial photography was obtained and showed excellent correlation with the 35mm photographs where relatively large scale phenomena were involved. In addition, the scale of the LANDSAT imagery allowed ranch personnel to qualitatively compare their results with those of neighboring ranches on a broad scale for the first time.

Late in 1973 the first LANDSAT CCT's over the area were obtained and input to IMAGE 100, General Electric's Multispectral Image Processing System. The IMAGE 100 analysis involved classification testing of signatures for the major study crops, experimentation with signature extension techniques between two of the firm's ranching areas, and differentiation of variations in vigor within crops. All of the IMAGE 100 work done at this point was part of the learning phase effort and was purposefully experimental and preliminary in nature.

The transition from Phase I to Phase II was marked by a visit of key ranch personnel to the GE IMAGE 100 facilities, during which time extensive analysis of the several tapes acquired was conducted. The visit was interesting in two aspects. Until this point, the ranch people had only been exposed to LANDSAT data in photographic form, and although transparencies and prints, at various scales both black and white and color, had been acquired, the ranch personnel found little of interest in the data. This was due at least in part to the fact that the data was always several months old. Once they were exposed to the capabilities of machine processing, however, the entire picture changed. They began immediately to understand the concept of multispectral data and to recognize what could be derived from it. In this respect this three day visit not only marked the transition from Phase I to Phase II, but more important, it marked a significant shift in emphasis toward the application of LANDSAT data.

The second important aspect of this visit was the amount of information which these professional ranchers were able to derive from the data using machine processing capabilities. Until this time, GE staff personnel who had spent the summer on site had used IMAGE 100 to operate on the data as described above, and had reported excellent results. For the most part, their efforts had been directed at signature development and classification of the major study crops.

The ranch personnel, working with the help of GE staff people, tended to concentrate on individual crops and even individual fields, and their knowledge and recall of conditions and events provided a wealth of new information from the LANDSAT data. Classification of major crops was quickly demonstrated and dispensed with, and the analysis sessions moved toward the identification of crop varieties. Three separate varieties of seed alfalfa were discriminated and accurately classified, all within the same image and all planted at the same time. Two adjacent fields of safflower showed considerable spectral differences, although no difference had been noted in visual inspection of the field at the time. This was especially significant since one of the fields had produced a much lower yield than anticipated.

Inyo and Anza, two varieties of wheat, were readily separated, as were several areas of lodged wheat. This, too, was important since the lodged condition was not known at the time, and the field had been irrigated and a large section had been destroyed.

PHASE II - THE PILOT PROGRAMS

Phase II took place from March through December 1974, and consisted primarily of two separate but related pilot programs: routine aircraft remote sensing for "real-time" farm management, and the use of LANDSAT data for large scale crop inventories.

Aircraft Survey Program

The aircraft survey program began with the installation of a nine inch camera in one of the ranch aircraft in April 1974 and continued through September 1974, the major part of the growing season for cotton. Color infrared film (2443) was used almost exclusively. The flight plan covered thirty-five thousand acres of the main ranch, plus twenty thousand acres of another of the firm's ranches some eighty miles to the south, every nine days, on a schedule which coincided, again, with the LANDSAT eighteen day coverage cycle.

As each photo mission was completed, the film was flown to a photo lab for processing and returned to the ranch for examination by GE and ranch personnel within twelve hours after acquisition. The results of the analysis were recorded and subsequently developed into a set of photo interpretation references, or keys, for use by ranch personnel. The film was indexed and filed by field with a mission number cross reference.

The imagery found application across the spectrum of ranch operations. The early detection of weeds and insect and rodent damage were among the first results. Cultivation problems such as planter and fertilizer skips were also quickly identified.

Perhaps even more important, a number of subtle, but significant phenomena were identified and monitored by virtue of the repetitive coverage provided. The affects of various crop rotation patterns, for example, were clearly depicted in the imagery, providing a qualitative if not quantitative assessment of the impact. The evaluation of several experiments involving crops, cultivation practices and/or equipment also benefited from the repetitive imagery.

In another application, soil types and certain mineral deficiencies were identified and mapped over both the major areas in cultivation and several new areas being developed. These results provided valuable new data for the company's land improvement program, and caused several changes in the projected program schedule.

Near the end of the season, repetitive aircraft imagery was used to map the drying patterns in both safflower and cotton. These maps, in turn, were used to schedule the application of desiccants prior to harvest.

Clearly, quality, repetitive coverage by aircraft provided valuable new data for ranch management, and while it is unlikely that this will ever replace the ground level, visual inspection to which they are accustomed, it does provide new data from a new viewpoint. It has also provided a permanent photographic record of the 1974 season - an exceptional season in view of the unusually low incidence of insects, disease, and other problems - as a basis for comparison in future years.

The results of this pilot program have led to the establishment of an operational survey program. The flight schedule has been refined to maximize coverage during critical crop growth periods, supplemented by periodic monitoring and special purpose flights. The operational program is being carried out entirely by ranch personnel.

Crop Inventory Program

The utilization of LANDSAT data for large scale crop inventories was of great interest to the firm's management. Their requirements for the inventory were two-fold: the earliest inventory of acres planted, with a corresponding accuracy of ninety-seven percent or higher. It is interesting to note that the emphasis throughout was on "acres planted", as opposed to yield. This results from the fact that sufficient historical data concerning yield already exists for their purposes, and only a measure of acres planted is required.

The pilot program in large scale crop inventories took the form of an inventory of cotton over some 4.8 million acres of the San Joaquin Valley. The inventory was carried out with LANDSAT computer compatible tapes and IMAGE 100.

The company's ranch served as the training and test site for signature development. Six different signatures were developed and employed to test extendability. These involved various spectral resolutions (32, 64, and 128 levels), as well as standard and band-ratioed combinations. All six signatures were applied over the study area, so that, in reality, six inventories were performed. The results were compared against data obtained from the California Department of Agriculture.

This pilot study did, in fact, produce an inventory of ninety-seven point two percent accuracy in measuring 650,000 acres of cotton in the 4.8 million acre study area. This was accomplished using LANDSAT data from early September, six to eight weeks before harvest.

A pilot study using multi-temporal classification techniques on a sample basis was also carried out. This showed that the same inventory could be produced as early as July, with the same or even higher accuracy, using data obtained on only two dates. The study also showed that operational inventories of this type could be carried out at a cost of much less than one cent per acre inventoried.

This activity demonstrated both the effectiveness and the efficiency of LANDSAT data for large scale crop inventories for the purposes of this particular agricultural firm. Certain technical developments are currently underway which will even further improve efficiency and reduce the time required to produce the operational inventory results. What remains is the need for a steady flow of LANDSAT digital data, in a timely manner, to make operational inventories a reality.

SUMMARY

The program described here represents the efforts of one major agricultural firm to become familiar with and apply remote sensing technology in its primary business activities. Certainly this is not an isolated case, but the study as a whole, and certain of the results are significant.

This particular agricultural firm is one of the largest and most successful in its field. Until this study began the company had no form of remote sensing activity other than the ranch manager's visual inspection of the field from the air two or three times per season. The success of this company is due largely to fertile land, an ideal climate, and a group of dedicated, experienced professionals, many of whom have been farming this land for almost twenty years. The ranch manager, for example, predicts the average yield for each field in August, eight to twelve weeks before harvest, and consistently produces a 98% accurate forecast. Attempting to improve on this level of performance is difficult to say the least, yet the study did demonstrate, among other things, that a basic form of remote sensing, aerial photography, could provide valuable new data.

It is important to recognize, however, that from the company's point of view, the value of the data did not lie in the ability to detect weeds and pests. These benefits did not adequately justify the cost. The real value lay in the ability of the imagery to map the soils and minerals, to monitor growth in new development areas, and, in general, to add to the basic knowledge of the land. The benefits of much of what was learned cannot be measured in tangible terms, but were considered sufficient to support a continued, operational activity.

Machine processing of LANDSAT digital data demonstrated the potential for applications in both ranch management and large scale inventories. This was recognized early in the program and enthusiastically supported by the firm's management. LANDSAT was particularly suited to many management requirements at the ranch because of the large area involved and the full section fields. The correlation obtained between the larger scale phenomena identified in the aircraft imagery and those subsequently found in the LANDSAT data was excellent. This, of course, leads to the conclusion that LANDSAT data could supplant the aerial photography in many ranch monitoring functions if it were available in real time. As a sidelight, it should be noted that the combination of LANDSAT, aircraft, and ground truth data collected over the ranch in 1974 comprises perhaps the most comprehensive set of multistage sampled agricultural data ever acquired in that area.

The application of LANDSAT to crop inventories was amply demonstrated, and since the time that this pilot study was conducted, GE has performed a number of other inventory programs, all of which have confirmed or improved upon these results. The important conclusion to be drawn here is that LANDSAT data and the current machine processing technology satisfied the major inventory requirements of this particular company. It is reasonable to assume that

the requirements of other firms could be satisfied as well. Certainly more testing and verification are required, but it does appear that the tools are at hand to satisfy many of the inventory requirements of the agricultural community. The limiting factor, currently, is the lack of data, routinely, in the time frame which these users require. Operational applications in both ranch management and large scale inventories require data in a time frame measured in days and perhaps weeks, certainly not months. It is difficult to imagine how one can look for this kind of utilization among the professional agricultural community until this capability is provided.

PRACTICAL APPLICATION OF REMOTE SENSING IN AGRICULTURE

A-18

By Richard A. Phelps, Anderson, Clayton & Co., Houston, Texas

N76-17486

ABSTRACT

During the past few years Anderson Clayton has utilized in their remote sensing program imagery from several types of platforms from light aircraft to the LANDSAT (ERTS) satellites. We prefer inexpensive imagery over expensive magnetic tapes. Emphasis has been on practical application of remote sensing data to increase crop yield by decreasing plant stress, disease, weeds and undesirable insects and by improving irrigation. Imagery obtained from low altitudes via aircraft provides the necessary resolution and complements but does not replace data from high altitude aircraft, Gemini and Apollo spacecraft, Skylab space station and LANDSAT satellites. Federal government centers are now able to supply imagery within about thirty days from date of order and deserve to be commended. Nevertheless, if the full potential of space imagery in practical agricultural operations is to be realized, the time span from date of imaging to user application needs to be shortened from the current several months to not more than two weeks.

INTRODUCTION

My company and I sincerely appreciate the invitation to report our remote sensing activities at this Earth Resources Survey Symposium.

Mr. Ronald Reagan, before he became Governor of California, and when he was sponsored by a company heavily involved in the space program, used to present a stirring speech to groups all over the United States (1). My wife and I were fortunate enough to be in the Dallas Freedom Forum audience one night in February, 1962 when he was interrupted by applause 31 times during delivery of what came to be called "The Speech".

My original reason for mentioning "The Speech" was that after reviewing material for this talk I realized that more or less the same speech had been given when our company was invited to participate in remote sensing sessions in Tucson (2), Memphis (3), Phoenix (4), NASA-JSC (5), Galveston (6), and in Washington (7). Obviously it was time to prepare entirely new material. Of course, if there had been an opportunity to present the talk a few thousand times, with new slides, then Mr. Reagan's style might be emulated a little more than will be obvious today.

Before leaving the subject of Mr. Reagan's speech, an address I highly recommend to anyone concerned about the future of the country and the space program, let us use a portion of it to relate current world conditions to agriculture. On page 7 of the February 1962 speech Mr. Reagan quoted a former Director of the Budget as follows, "The greatest threat to our nation today is not Berlin nor is it Viet Nam, or the Congo, or Laos. It is the precarious situation of our balance of international payments and with it the potential erosion of the world's confidence in the dollar."

In 1974 the United States exported agricultural commodities valued at approximately 22 billion dollars while importing only about 10 billion dollars worth (8). Yet during the same period we exported nonagricultural goods valued at 75 billion dollars while importing 90 billion dollars worth. Thus despite almost a 12 billion dollar trade surplus of agricultural goods from efficient American agriculture we ended the year with a total trade deficit of over 1.5 billion dollars (9).

A thought provoking analysis of our agricultural exports by a former member of the Hudson Institute contains the following sentence in the preface, "American dominance of the agricultural export market is greater than Arab dominance of the petroleum market" (10).

The main body of the report provides impressive supporting evidence. Thus, the value of the dollar and our political influence in the world seems to depend on maintaining an efficient agricultural system. Furthermore, we must accomplish this in the face of increased problems created by people who appear to many agriculturists to do a remarkable job of concealing any knowledge they may have of agriculture. Yet these same people distinguish themselves by generating regulations which lead directly to increased food costs for all of us. America certainly needs whatever production efficiencies can result from the wealth of remote sensing data being generated. Let us turn to the practical application of this data.

1971-73 REMOTE SENSING ACTIVITIES

Our remote sensing efforts from the spring of 1971 through the fall of 1973 have been outlined in several reports (2-7), so I hope a brief summary will suffice.

Our main objectives have been to utilize color infrared photography and scanner data for (a) detecting potential areas of severe disease and insect infestation in cotton and (b) for improving irrigation, weed control, etc., in a wide variety of crops.

The initial experience with color infrared photography of commercial fields encouraged us to "back-track" to experimental plots where we could more easily correlate false color tones with irrigation treatments, cotton varieties, weeds, etc. When we returned to the study of commercial fields we were able to differentiate, via color infrared film, several types of weeds, short vs. long staple cottons, land leveling scars, water stress, inadequate irrigation, salinity effects, herbicide damage, wilt disease, etc. We are still unable to identify nematode damage in commercial fields via color infrared photography and have detected several unusual tone patterns which remain unexplained.

In earlier reports we also indicated that our choice of color infrared photography and infrared scanner data was governed by practical considerations. We still believe it was the proper choice but realize that other portions of the electromagnetic spectrum yield valuable data.

In previous talks we commented on the apparent dearth of qualified interpreters of color infrared (false color) film, at least as far as cotton is concerned. We still have not located the person who can look at film of commercial cotton fields and differentiate, for example, cotton stressed for water vs. cotton infected with nematodes.

The serious problem of excessive delays in obtaining satellite and other types of remote sensing data through the EROS Data Center was also mentioned in earlier reports. During the past few months the EROS Data Center has greatly improved their service and deserve to be commended. Until the time period from satellite sensing to user receipt is shortened to about two weeks, however, agricultural application of such data cannot achieve full potential.

1974 REMOTE SENSING PROJECT

During the summer of 1974 we filmed more than 10,000 acres of cotton in Central Arizona as part of our continuing program to detect and control a damaging boll rot problem and to improve cotton cultural practices.

In earlier reports we emphasized the serious nature of the boll rot problem. A particular type of hot weather-loving mold infests cotton bolls that have been previously attacked by insects and produces undesirable by-products in the <u>unharvested</u> bolls. These mold products remain in the cottonseed during harvest and survive the high temperature and pressure used to convert the cottonseed into cottonseed meal used for animal feed. If the cottonseed meal contains more than 0.000002% of these mold products the meal cannot be shipped interstate.

The small amount of mold products, 0.000002%, may be more easily perceived if viewed in the context of space, time and joy. Twenty parts per billion (0.000002%), or 20 micro-

grams per kilogram, is about 20 feet along a line to the moon or 20 seconds in 32 years. For the dry martini connoisseur it is 20 jiggers of vermouth in 1000 railroad tankcars of gin.

Extensive field sampling of cotton during the past few years has indicated that most of the boll rot problem in Arizona, for example, was confined to the lower elevations and appeared to be more of a problem near irrigation canals and citrus orchards. Since we expect high humidity near canals and know that citrus trees are planted in what are hoped will be frost-free areas we have some important clues to our problem. Nevertheless we were still unable to locate anyone who could with certainty identify which cotton fields contained seed with the mold by-products. The only way to be certain that cotton bolls in a particular field contained the mold products was to harvest several samples of 100 bolls each, remove the lint (gin), dehull the seed, grind the kernels and analyze the extracted ground kernels by a laborious chemical test called thin layer chromatography. With 425,000 acres of cotton in Arizona yeilding over 260,000 bolls per acre (at 2 bale/acre yield) or 167 million bolls per section (1 square mile or 640 acres) of land, it is easy to see the impracticality of widespread field sampling by conventional methods.

Several years ago we tried to develop a more sophisticated system. A 70 acre field of Arizona cotton that Herb Schumann of the USGS had photographed with color infrared film on several occasions during the peak of the growing season was sampled extensively. We learned from that study that the mold products were more prevalent in the over-irritated portions that could be detected by heavy leaf canopy and crimson tone, and were essentially absent from water stressed (under-irrigated) portions.

In the summer of 1974 we extended the above study to more than 10,000 acres. Unfortunately, Mother Nature did not cooperate because we could not find an area within the 10,000 acres that displayed a high level of the mold products. The highest level found, however, was in an area of relatively rank, solid planted cotton. We are reasonably certain that improper irrigation, failure to dissipate humidity beneath the leaf canopy and poor insect control are major factors in producing the boll rot-mold product complex. We are also attempting to solve the problem by genetically altering the cotton plant.

Unfortunately we have not adequately measured the role of insects in the mold problem. Most of the boll rot and much of the insect damage is usually on the lower third of the cotton plant and shielded from view by the extensive leaf canopy. In addition, the boll rot and associated ultraviolet fluorescing lint are usually inside an unfluffed cotton boll and not detected until the boll is torn apart. Consequently we have been forced to employ indirect, rather than direct, means of detecting the condition by remote sensing. If the sophisticated and capable engineers are able to develop a direct and practical method for detecting internal boll rot and/or associated mold problems, they will receive considerable attention.

While this talk has concentrated on the boll rot aspect of our 1974 project, we did study and detect other serious cotton problems. Cotton stunted from presently unknown causes, root rot, water stressed cotton, unfavorable soil conditions, etc. were all clearly visible on the film.

One unexpected result from the 1974 filming was the detection of a 230 ft. x 100 ft. NW-SE oriented rectangle in one of the Arizona cotton fields. The rectangle had not been detected prior to developing the film despite considerable activity within and around the field. Within the rectangle the cotton was approximately a foot taller than surrounding cotton in the same field and displayed more wilt. High altitude January film of the same area indicated the rectangle may be at least partially visible when the field is fallow, but a ground check in April 1975 showed nothing but a slight ground depression in one portion of the rectangle. The purpose and origin of the rectangle remain a mystery, but possibly the archaeologists have a ready explanation.

"OVERSELLING" OF THE SPACE PROGRAM BENEFITS

During the past few months we have received several communications which contained criticism of the space program. The common complaint seems to be "overselling" of the program and particularly the capability of the LANDSAT satellite. It might be preferable to term it "improper selling". We have found LANDSAT and Skylab transparencies to be very helpful for (a) providing relative crop and soil conditions over wide areas, (b) permitting comparison of one or more crops between adjacent farms, (c) measuring relative acreage of a particular crop within a large area, (d) "learning the territory", etc. Magnetic tapes cannot substitute for imagery for some of the above objectives. If we need detailed data on weeds, irrigation, etc., we use large-scale aircraft imagery. There is no more reason to expect the LANDSAT satellite to detect small area weed problems than there is to expect the Queen Mary to tow a water skier. Realization of the proper role of each type of "platform" sensor, tape and image should reduce the complaints and increase the appreciation of this most valuable "tool" for agriculture.

REFERENCES

1) What Price Freedom?, Ronald Reagan, 27 Feb., 1962, Published by Dallas Freedom Forum, Fidelity Union Tower Lobby, Dallas, Texas.

2) Aerial Photography and Fungal Infestation of Cotton in Maricopa County, 5 Nov., 1971, Richard A. Phelps, Proc. 2nd ARETS Symposium, Tucson, Arizona.

3) Remote Sensing Project in Arizona, Richard A. Phelps, 11 April, 1972, Report to Spring Meeting of Research and Education Committee, National Cottonseed Products Ass'n., Memphis, Tenn.

4) Remote Sensing in Agriculture, 25 Jan., 1973, R. A. Phelps, West Coast Oilseeds Development Council Annual Meeting, Phoenix, Arizona.

5) Practical Application of Remote Sensing in Agriculture, 30 May, 1973, Richard A. Phelps, Skylab Press Conference, Johnson Space Center, NASA, Houston, Texas.

6) Practical Application of Remote Sensing in Cotton Production, 19 June, 1973, Richard A. Phelps, International Oil Mill Superintendents Ass'n, Galveston, Texas.

7) Remote Sensing and Agricultural Productivity, Richard A. Phelps, 29 Jan., 1974, American Institute of Aeronautics and Astronautics, 10th Annual Meeting.

8) 1974 Handbook of Agricultural Charts, Agricultural Handbook #477, Oct. 1974, USDA, Washington, D. C.

9) Personal Communication, 22 May, 1975, United States Department of Commerce, Houston, Texas.

10) Can We Avert Economic Warfare in Raw Materials? U.S. Agriculture as a Blue Chip, 1974, William Schneider, National Strategy Information Center, Inc., 111 E. 58th St., N.Y. 10022.

OMIT

A-19

NEED FOR REMOTE SENSING IN AGRICULTURE

by Hosea S. Harkness, Cook Industries, Memphis, Tennessee

The preceeding papers have told us the job can be done. Now, let's look at why it needs to be done. We hear and read daily in the news media that world population problems are leading to world food shortage.

First, let's set the stage as to why remote sensing is needed in agriculture and more specifically in relation to the marketing of agricultural commodities by looking at the 1960's. In 1960, we had enormous stocks of grains in the U.S. and throughout the world. Crop disasters developed early in the 60's in a few parts of the world. By mid-1960, our Secretary of Agriculture was telling us the United States had the responsibility of feeding the world. This was a little premature since there still existed means by which the producers of the world could recover from this disaster. Expanded crop land area, coupled with good weather, led to the recovery, and once again grain surpluses occurred. However, this recovery was only for the short run.

Moving into the 1970's, the U.S. was immediately confronted with a combination of corn blight and drought. This was probably one of the worst crop disasters that had confronted a single crop since the potato famine in Ireland in the 1800's. In 1971, grain crops were good throughout the world. Then 1972 came with adverse weather early in the year in Australia and Argentina. A poor winter in the U.S.S.R. was followed by a poor growing season for small grains. Suddenly the fish were gone from the coasts of Peru. In late 1972, excessive rain hit the U.S. harvest. Early 1973 drought occurred in South Africa followed by excessive rains at harvest time in Argentina. Thus, suddenly the demands for grain were greater than the 1972 supplies and large quantities of the then existing surpluses were utilized.

In 1974, once again there were many problems as excessive rain delayed planting of the U.S. crop followed by a mid-summer drought and early crop-killing frosts. Excessive rains have once again hurt the Argentina harvest in early 1975 and Australia, which had poor weather last year, is continuing to be confronted with dryness. Late planting seasons occurred in Europe while severe drought sharply reduced production in North Africa.

Along with this, we had the affluent societies of the world in 1972 demanding less carbohydrates and more proteins. The free economies had more money to spend and the state controlled economies wanted to upgrade their standards of living.

The result has been the depletion of world surpluses. We have not been able to recover quickly as we once could. Land is now a limiting factor and where there are expansion areas in the world, they are slow in developing due to political or economic reasons.

In looking to what lies ahead, we have Bangladesh where there are seven births each minute; India where the population density is over 425 per square mile. Medical care in many parts of the world extends the survival of infants considerably from that of a few years ago. World population by 1980 will be up 13 percent and we will have over 4.25 billion inhabitants.

This is the stage that is set. To solve this situation, we need an informed public. Why an informed public? Because an informed public operating in the market place provides an orderly market place. There will be less risk involved and all involved, even the farmer, have the opportunity to maximize their profits.

In looking at today's world information systems, we have a few countries that are sophisticated data collectors; we have a group of countries that may be sophisticated but they won't release their information because of political reasons; and there are countries with essentially no information. We must keep in mind that unbiased statistics are not manufactured but are collected.

With an informed public, the farmer and agri-business community can react. Today, we are at a disadvantage in the world because of lack of information. If we knew the exact situation, transportation systems could distribute agricultural commodities more efficiently. The merchant could have a competitive advantage and operate on a lower margin. The affluent consumer throughout the world would not have to over-react and hoard foods. The best examples are the scare we had on meat two years ago and more recently the sugar shortage.

If we are to solve these problems, we need a better worldwide information system. Little can be done to improve the sophisticated countries, only their warning system can be improved. However, much can be done to improve the systems of the unsophisticated data collectors of the world.

Remote sensing offers the basis for a uniform information system. It has the ability to give worldwide coverage on a continued and timely basis.

The kind of information that remote sensing could provide to the sophisticated countries would be an early warning of crop stress; be it moisture, disease, insects, or crop progress development. In all other countries, remote sensing could provide a basic cropland inventory so that everyone has a common base to work from. Once the base was obtained, these countries would also need early warning of crop stress factors.

After we have learned how to handle the crop stress factors, we will learn how to develop crop yields, which countries that are not currently surveyed by other means could utilize. Other disciplines working on soil moisture and temperatures, etc. would be utilized in understanding crop yields.

In conclusion, we need an information system that collects crop data on a comparable and timely basis. This system must then inform the individual countries and the world so that the market place can be alerted to taking corrective action. Again, remote sensing offers that basis.

1/ E-1

WILDLIFE MANAGEMENT BY HABITAT UNITS -- A PRELIMINARY PLAN OF ACTION

By Carl D. Frentress, Wildlife Biologist, and Roy G. Frye, Wildlife Biologist, 6120 Highway 290 West, Austin, Texas

N76-17487

ABSTRACT

The Texas Parks and Wildlife Department recognizes the need for managing populations of wildlife species by defined area units. A data stratification scheme is required to investigate species populations for the purpose of identifying unit boundaries. Vegetation type maps are commonly used to stratify data collection points, and subsequently delineate boundaries of homogeneous populations.

Procedures for yielding vegetation type maps were developed using LANDSAT data and a computer assisted classification analysis (LARSYS) developed by Purdue University. Ground cover in Travis County, Texas was classified on two occasions using a modified version of the unsupervised approach to classification.

The first classification produced a total of 17 classes. Examination revealed that further grouping was justified. A second analysis produced 10 classes which were displayed on printouts which were later color-coded. The final classification was 82 percent accurate. While the classification map appeared to satisfactorily depict the existing vegetation, two classes were determined to contain significant error.

In the eastern portion of the county eastern red cedar (Juniperus virginiana) intermixed with post oak (Quercus stellata) was classified as an ashe juniper (Juniperus ashei)-live oak (Quercus virginiana) association. Also the class representing a composite of ashe juniper, live oak, mesquite (Prosopis glandulosa), and bluestem (Schizachyrium spp. and Bothriochloa spp.) of various physiognomic patterns as depicted on the classification map did not in some cases match species composition on the ground. A review of the procedures indicated that the major sources of error could have been eliminated by stratifying cluster sites more closely among previously mapped soil associations that are identified with particular plant associations. This could have served as a safeguard to prevent overlooking a vegetational class. Also, error could have been reduced by precisely defining class nomenclature using established criteria early in the analysis. A procedural plan has been developed which reflects modifications of the initial procedures developed in the Travis County study.

INTRODUCTION

Texas is experiencing rapid changes in land use. Domestic pasture grasses have been planted on many former croplands and woodlots. Ranch lands are being sold to developers and parceled out as "ranchettes", resorts, or suburban developments. Even-age silviculture with its attendant monotypic character is now practiced over much of the Pineywoods ecological region, and brush-clearing has greatly increased in the South Texas Plains. All of these changes have serious detrimental effects on wildlife. Natural habitats are shrinking drastically while the consumptive and nonconsumptive demand for wildlife increases. Thus, a vital need exists to inventory the remaining wildlife habitat.

The objective of this pilot study was to develop techniques for producing ground cover type maps compatible with current needs in wildlife management in Texas. Such an inventory is necessary for two different but related reasons. The first relates to game management. During 1974 the Wildlife Division of the Texas Parks and Wildlife Department implemented a series of programs based on species management concepts. These programs require an evaluation of wildlife species populations and their portrayal by management units.

1/ A contribution from Federal Aid to Wildlife Restoration Program, Texas, Pittman-Robertson Project W-107-R.

By stratifying measurements of animal population dynamics within plant associations, biologists can obtain a measure of the character and extent of homogeneous populations. Biologists may then begin to delineate species management units. Delineation of management units is essential for the determination of carrying capacity, range condition, harvest recommendations, and population trends .

The second reason for this inventory pertains to long-range planning. By knowing the identity, location and quality of the natural habitats and the impinging factors, managers may begin to propose rational alternatives to minimize losses of habitat brought on by industrialization, urbanization, water development projects, and other land uses.

The inadequacy of previous techniques for large-area mapping of ground features is reflected in the existing vegetation mapping literature for Texas. Winkler (1) presented an account of the activities of early botanists working in Texas. Most of the subsequent works were descriptive only in floristic terms, or were regional in application (2, 3, 4, 5, 6, 7 and 8). Tharp (9), Gould (10), and Kuchler (11) have published statewide presentations of vegetational areas of Texas; however, the contents are too gross for proposed wildlife management objectives.

The advent of remote sensing technology has opened new means of evaluating the environment for natural resource managers (12, 13). Initial applications of remote sensing products in the United States involved interpretation of high-altitude aerial photography or orbital imagery as exemplified by MacConnell and Garvin (14), Hay (15), and Cowardin and Myers (16). However, the versatility and objectivity of computer assisted analysis of digital data from spacecraft equipped with multispectral scanners is now being tapped for large-area land inventories (17, 18, 19). Computer technologists have developed operational or near-operational hardware and software to serve land resources analysts in this capacity (20, 21, 22). Current trends indicate a rapidly expanding field of remote sensing technology which has application to wildlife management, particularly in the area of habitat mapping.

STUDY AREA

Travis County, located in south central Texas, is considered to be one of the most topographically diverse counties in the state. The occurrence of the Balcones escarpment which runs through the center of the county creates two major geographical areas, each possessing significant topographical features. The western portion of the county is characterized by higher elevations, steeply sloping hills and ravines, abundant cliffs and limestone outcroppings, and generally shallow soils. This region represents part of the eastern edge of the Edwards Plateau. The eastern portion of the county exhibits generally flat or gently sloping terrain, with shallow to deep soils and is within the Blackland Prairie ecological region.

Such topographical differences permit the occurrence of numerous and diverse plant communities. The dominant woody plant species in the western portion include mesquite, ashe juniper, live oak and Texas oak (*Quercus texana*). Ranching is the predominant land use activity in the western portion of the county.

Eastern Travis County supports mesquite, eastern red cedar, live oak, post oak and bluestem grasses on the upland areas, with hackberry (*Celtis laevigata*), cedar elm (*Ulmus crassifolia*), and pecan (*Carya illinoensis*) occurring in lowland areas. Additionally, a large portion of the eastern half of the county is used extensively for agriculture. Cotton and grain sorghum serve as the main crops. The central portion of the county contains the city of Austin with its associated suburbs.

METHODS

A modified version of the unsupervised classification approach was employed to produce a classification map of Travis County. This was a test analysis to develop procedures

for producing classification maps over the entire state. The unsupervised technique is an analysis approach developed by the Laboratory for Applications of Remote Sensing (LARS), Purdue University, West Lafayette, Indiana, for use with their computer-assisted analysis system (LARSYS-Laboratory for Applications of Remote Sensing System). Digital data obtained March 17, 1973, from LANDSAT were used for this classification.

The unsupervised approach consists of determining spectrally distinct classes within portions of a scene using a clustering algorithm (Appendix A) and later identifying these spectral classes as different types of ground cover. The efficiency of this procedure was increased by stratifying the location of the cluster sites according to the predetermined general distribution of ground cover classes.

Gray-scale printouts showing raw data for Travis County and vicinity were generated at every fifth pixel in each of the four channels of LANDSAT data. A pixel is the smallest resolvable element in multispectral scanner data. The printout for the near infrared channel was used as an orientation base since the bodies of water and major highways were best defined in this channel and could be outlined with map pencils.

These gray-scale printouts of every fifth pixel were similar in scale to the 1:126,000 scale general highway maps for counties in Texas. Consequently, more orientation features could be marked by overlaying the printout on a general highway map for Travis County.

Aerial photography of Travis County with an approximate scale of 1:63,000 was used to stratify the cluster sites. All portions of the photographs were visually examined to ascertain general topographical, and physiognomic characteristics. Stratification was accomplished by using these observations to determine the location of major plant associations, water bodies, and areas heavily influenced by man. A total of 13 sites was selected for use in the clustering process (fig. 1). A majority of these sites contained 2500 pixels. A maximum class notation (maximum but variable number of classes that the clustering function will depict) value of eight was designated on the control cards for each cluster site. Printed output included cluster maps for each site and separability information from the interclass divergences for each site. Punched output included training field description cards for each spectral class occurring within each site. A training field is a set of data that represents a class to be delineated. The separability information was used to group spectral classes and determine whether a larger maximum class value was needed. Classes having a quotient value of 0.75 or less were grouped together. If none of the quotient values were less than or equal to 0.75 for any given site, the clustering procedure was conducted again for that site with an increased maximum class value of 10.

Patterns of spectral classes appearing on each of the cluster maps were colored with map pencils to simplify recognition. These maps were taken into the field to each of their respective locations to identify the spectral patterns with actual ground cover. Names corresponding to the existing ground cover were given to each cluster site according to these observations.

The training field description cards of the 13 clustered sites were grouped under the categories of ground cover established from the field checks. Identical categories of ground cover occurring over all of the clustered sites were grouped together. Care was taken to establish definitive class categories by grouping all explicitly confirmed classes and not attempting to combine any classes appearing to overlap. For example, the category identified as live oak - bluestem savannah was grouped separately from the category ashe juniper - bluestem savannah.

The training field description cards, grouped according to classes of ground cover, were input into the statistics processor (Appendix A). The appearance of the histograms generated for each class in each of the four channels served as a measure of their statistical desirability in later training the classifier. Histograms exhibiting Gaussian distributions served as indicators of acceptable class groupings. Classes with unacceptable,

multimodal histograms were manipulated through adjustment (combination or deletion) of the ordering of field description cards and additional statistical processing until acceptable histograms were obtained.

Final output from the statistics processor was used as input into the separability function (Appendix A) to determine whether further grouping or lumping of the classes was justified. Paired classes with transformed divergence values of 1,500 or less were grouped together. This was accomplished by combining the training field description cards for these paired classes into one group.

After the statistics processor was used to insure a Gaussian distribution of reflectance values within each class, the resulting statistics file was input into the classification and reporting processors (Appendix A). These processors produced a classification map on a computer-generated printout with cover types portrayed by alphanumeric symbols.

RESULTS

Two classification analyses were performed for Travis County. The first classification produced a total of 17 classes. Examination of these findings indicated that further modification in class groupings was justified to improve classification accuracy and facilitate interpretation of the final map. Modifications were made and a new statistics file was obtained. The second classification analysis produced 10 classes which were displayed on the printouts using revised alphanumeric symbols which were later color-coded. The statistical accuracy by class of the classification output was approximately 82 percent.

The final classification results of Travis County at the approximate scale of 1:24,000 were checked at actual field locations to determine credibility. While the classification map appeared to satisfactorily depict the existing vegetation, two classes were determined to contain an unacceptable degree of error.

In the eastern portion of the county eastern red cedar intermixed with post oak was classified as an ashe juniper - live oak association. This situation is exhibited in the classification map portrayed at every fifth pixel in Figure 2. Also, the class representing a composite of ashe juniper, live oak, mesquite and bluestem grasses did not, in some cases match species composition on the ground. These observations and a review of the test analysis procedures indicated that the major sources of error could have been eliminated by stratifying the cluster sites more closely among previously mapped soil associations that are identified with particular plant associations. This allows a safeguard to prevent overlooking a vegetational class. Error could also have been reduced by precisely defining class nomenclature using established criteria early in the analysis.

DISCUSSION

A procedural plan has been developed which reflects modifications of the initial procedures developed in the Travis County studies. This plan will guide the development of vegetation type maps required for biologists to proceed with delineation of species management units. The following is a narrative description detailing the procedures proposed for conducting a comprehensive vegetational type mapping inventory for the State of Texas. The inventory will be conducted utilizing remotely sensed data in digital form obtained from the LANDSAT-1 and processed through capabilities of computer-assisted analyses.

Our classification output will be multilevel in content. That is, natural areas will be classified more intensively than urban or agricultural districts. The final maps will portray detailed plant association patterns and generalized agricultural and urban patterns.

Based on wildlife management needs, we believe the plant association level (descriptive in floristic - physiognomic terms) will be most practical for application of the classification products. For the purposes of this vegetation mapping, the following

proposed working definition is submitted:

> A plant association may be defined as two or more dominant plant species growing together, exhibiting a similar life form and generally characterizing the flora of the geographic area where they occur. Of course, at seral stages below climax the prevailing plant species which typify the association will not be the climax dominants. Nonetheless, these plants comprise the association type of the existing vegetation. A consociation is as above but only one plant species is dominant in the sere.

This definition was derived from Kuchler (23), Oosting (24), and Weaver and Clements (25).

Delineation and classification of ground cover will be accomplished by computer-assisted analysis. The analysis will involve stepwise processes that follow logically to a final classification of ground cover (fig. 3) .These results may be shown as alpha-numeric symbols which are printed on paper or as colored patterns which can be visually displayed on an electronic screen (26).

The initial step in the computer-assisted analysis procedures will be to obtain basic information for the data to be investigated. Output from this function provides basic references on location of the frame, date and time of overflight, serious deviations in the scanner system, and other information of importance related to the bulk data.

Gray-scale printouts containing desired data will be obtained through display of every fifth pixel in each of the four channels of LANDSAT data. The gray-scale for band 6 seems most useful as an orientation tool and work map since roads and water are best defined in the raw data from this near infrared channel, however, other useful orientation information can be obtained by examination and comparison of the gray-scale printouts of data from the other three channels. The fifth pixel scale (approximately 1:125,000) closely approximates the county highway maps and facilitates transfer of orientation features from the highway map to the gray-scale printout.

Supportive information previously gathered from other vegetative studies, information provided by district biologists, examination of aerial photography, LANDSAT imagery, and topographic maps will be used to familiarize the analysts with the general floristic and physiognomic characteristics of the expected vegetation and determine locations of representative vegetational classes throughout the scene. This will be accomplished through district staff briefings and regional field tours. Previously documented maps containing information related to changes in land use, vegetation, soil types and range sites of Texas will be extensively examined to provide an overview about vegetational patterns that potentially exist in the area to be studied. Training received by the analysts in the staff briefings will be exercised in practical botanizing during the field trips. Also, during these tours land use and urban development will be observed. This will acquaint the analysts with the cultural features peculiar to the region.

With this supportive information assembled, the analyst should proceed with the next processing step, the clustering function. This step determines the number of classes represented within any area of the scene delineated. To amply represent all expected classes within a scene, a number of cluster areas should be chosen systematically. Careful scrutiny of aerial photographs at this point is necessary to more knowledgeably select areas containing classes of interest.

In addition to attempting to represent particular sets of classes the analyst should also exercise care in adequately orienting the placement of these cluster areas. Specific landmarks or orientation points should be contained in these areas to facilitate total orientation of the field party when ground truth information is collected for the purpose

of naming respective cluster classes. Roads and cultural features will be traced onto the cluster maps from 1:24,000 topographic maps when possible. In most instances positive ground identification of the cluster classes cannot be accomplished unless the field party is oriented perfectly with respect to the cluster map. Careful study of aerial photographs of the candidate site will be made to insure that the area can be recognized in the ground truth step. With background information on the potential number, kinds, and locations of classes, the analyst can make better decisions related to the required number and strategic placement of the cluster areas. These decisions will determine whether the analyst encompasses all the classes of interest in the data.

Once a cluster area is located and processing for cluster classes begins the analyst is confronted with the question of how many classes of interest may be obtained from the particular data to be clustered. This number must be determined for use in entering maximum class (maximum but variable number of classes that the function will select) notations on the control cards. The generally accepted rule of twice the number of classes expected (for the cluster site) will be applied. Indication of the adequacy of any given maximum class value can be noted by examining the quotient values in the separability information listed in clustering output. At least one quotient value of 0.75 or less should be noted. If no values are less than 0.75, the maximum class designation should be elevated at least by one (perhaps two) and the clustering function run again for that site.

Clustering functions should be run for each of the designated areas and appropriate output obtained. Punched output should be obtained as in the unsupervised approach which allows the computer to select classes and training fields. Immediate evaluation of the output from clustering is undertaken at this point. Decisions based on the separability information (quotient values) from interclass divergences are made and class groupings should follow which conform to these decisions. Dr. Edward Kan of Lockheed Electronics Corporation, Lyndon B. Johnson Space Center, Houston, Texas, advises that Laboratory for Application of Remote Sensing, Purdue University, favors grouping classes with values less than 0.9 (Personal Communication 1975). Utilizing these higher values to govern the grouping rule at this point could reduce grouping problems arising from the separability function later in the classification analysis. On the basis of these groupings the various classes should be delineated through colored patterns displayed on the respective cluster maps.

Accurate ground truth information must be gathered at this point by a field investigator. Ground truth will be recorded on the Training Field Record (fig. 4). The colored cluster maps serve as vital references in gathering this information. Also, aerial photographs, topographic quadrangle maps, and county highway maps assist on-site determination of ground truth.

The magnitude and scope of a complete statewide vegetation study of this nature prohibits the use of time consuming quantitative measurements to devise vegetation class nomenclature. A technique which will satisfy project objectives within a minimum time frame will be used. This technique will involve fitting ground truth information obtained by field checks to previously established criteria for name designation. Such criteria will include a floristic-physiognomic description of currently existing plant associations. Dominant plant species (floristic components) within areas under study will be visually determined. Measurements of two physiognomic parameters, average height and amount of canopy cover (crown coverage projected vertically over the ground surface), will be obtained at the specified locations using an ocular method similar to the technique described by DeVos and Mosby (27). These ocular skills will be developed by initially measuring height and canopy cover objectively. Height will be measured by field applications of hypsometer techniques described in Forbes (28) and/or with a clinometer. Crown cover will be measured from aerial photographs by application of the crown density scale described by Avery (29) or by on-site woody belt transects modified from Hahn (30). After an initial experience with these measurement techniques the analysts are expected to acquire skills adequate to allow acceptable subjective ocular estimates of height and crown cover.

The initial physiognomic descriptions (Appendix B) will be similar to those stated in Haas and McGuire (31). However, due to later class grouping dictated by analysis functions discussed previously, final designation of class nomenclature will vary accordingly. Con-

sequently, nomenclature for all types or subtypes of vegetation found in Reference 31 or all similar classes found in Levels II and III of the land use classification system devised by Anderson et al. (32) may not be represented.

Due to the boundary limitations of the clustering function, duplications and similarities occur in the cumulative class list as the analyst proceeds with cluster processing across the scene. Through evaluation of histograms, statistics, and separability values the analyst strives to combine the duplications, detect the degrees of similarity and catalog the separations. By these processes a list of classes of interest is gradually developed. Only by applying thresholding values (Appendix A) can the analyst gain indication that a class or classes may have been overlooked. However, wise application of supportive materials such as aerial photographs and potential class hierarchies can reduce the chances of missing a class of interest.

Additionally, classification accuracy would be increased in ecotonal areas or those having a wide diversity of ground cover and potentially containing a large number of classes, if such areas were subdivided into portions with each subdivision analyzed separately. Although more than one classification analysis would be needed, each process would be simplified due to representation of fewer classes within each subdivision.

The next major step in analysis involves evaluation of statistical information primarily in the form of class histograms and transformed interclass divergences. In any classes formed through grouping of two or more subclasses, the analysts should examine immediately the characteristics of the class histograms. Histograms should exhibit normalized distributions. The Gaussian distribution is a basic assumption built into the maximum likelihood classifier employed in the classification process (33). Training data must meet this qualification. Classes exhibiting strong bimodal or multimodal histograms should be re-evaluated and an effort made to correct this undesirable situation. At this point the transformed divergence values from separability function become the key indicators to further class groupings.

When final class groupings have been accomplished to the satisfaction of the analyst, a final statistics and separability run should be made. The statistics file that is developed will be utilized for the classification process. The separability run may not be particularly necessary at this step provided the analyst has been most perceptive and made no mistakes. Perhaps this run serves best as an "insurance" check on all decisions to this point and as an analysis landmark to lend credence to the performance ratings. The analyst should be able to proceed to the classification (Appendix A) function as the next step.

In the classification function a maximum likelihood classification scheme assigns all data points under consideration to one of the classes represented by the refined training class statistics (33). Thus, this processor will evaluate and classify all data points into the specified classes whether or not all classes in the scene are represented in the training statistics. Consequently, an overlooked or unrepresented class would be obscured through classification of its data points into the represented class that statistically most closely resembled the unrepresented class. However, detection of an overlooked class can be remedied through statistical thresholding options that may follow immediately after the classification function in the computer job string.

By classifying every pixel in the scene the analyst provides for later options related to varied scale. That is, if every pixel is classified then the scene can be portrayed on the basis of every pixel (approximately 1:24,000 scale), every second pixel (approximately 1:62,000 scale), etc. according to the desires of the analyst or user. This is in contrast to conducting the classification function on the basis of other than every pixel.
Such action would result in forfeiture of the capability to portray the scene in more detail than the degree employed in the classification process. We have elected to classify on the basis of every pixel since expected as well as yet unrecognized uses for the classification results will require the versatility of this type output. Thus, the classification

processor is essentially a straightforward function designed solely to produce sets of classified data points obtained through methodical comparison with refined training class statistics. No lengthy results, evaluations and decision-making steps are associated with this processor. The resulting classification will be stored on magnetic tape rendering these results available for practically unlimited temporal usage.

The reporting function, a follow-up processing stage to the classification function, provides various options for manipulation of classification results for the purposes of evaluation and application. The analyst may obtain printed maps, request performance tables, omit class symbols, detect overlooked classes, vary the scale (pixel designation) and/or select a portion of the classified scene. Additionally, this function yields insights into classification accuracies and provides total acreage figures for the various classes in any area of any size. A reporting job including performance options (accuracy evaluations) always follows the classification job.

The final results of the classification process will be checked for accuracy prior to the cartographic conversion. This will be accomplished by examining training field and training class performance values provided by the reporting function and verifying the final vegetational patterns indicated by the computer analysis. Suspected classification errors will be compared to the ground truth information derived from aerial photographs or on-site field inspections and corrected prior to final cartographic processing. Extensive classification errors may require reanalysis of the data.

Furthermore, we wish to mention the indirect capabilities this system will allow. We suspect that discrete spectral signatures cannot be developed for plant associations in all cases. However, we do believe the system is highly reliable in delineating broad classes such as forest, grass, etc. While detection of these broad classes is a limitation to the direct approach described above, this capability becomes an asset when linked to the descriptive material for soil associations. These soil associations already are described in published soil maps and legends. Thus, if only the physiognomic classes (e.g. woodlands) can be delineated through computer-assisted pattern recognition, refinements to provide the floristic components can be made by utilizing the information from soil mapping materials. In this manner, the desired plant association patterns can be determined.

The analysis for pattern recognition will be completed and subsequent tasks will deal with cartographic aspects. The computer printout "maps" alone are limited in application. Therefore, the results displayed on the printouts must be rendered into more practical map form. Techniques for producing desirable map products are being explored and tested for operational utility.

Generally, these cartographic approaches involve sophisticated electronically oriented procedures involving computer-controlled display screens that yield colored photographic prints of classified scenes. These methods are under experimentation by the Remote Sensing Center, Texas A&M University and Johnson Space Center, Houston, Texas. Output in the form of colored photographic mosaics from image display screens are expected.

The final products will be base maps in 1:126,000 scale with the ground cover classes in color codes. Illustrated narratives of legends will provide descriptive information for each of the classes portrayed. Also, the base maps will contain most of the information present in county highway maps presented in the same scale. This information would include such features as roads, urban areas, stream courses, etc. Inclusion of this information from the highway maps is essential to lending orientation attributes to the base maps.

CONCLUSIONS

With the rendition of the classification results into base maps biologists will use the vegetation type maps to begin the job of delineating species management units. The

first task apparent to the wildlife manager is to determine the habitat of the animal species under investigation. The user of vegetation type maps must integrate existing information on animal habitat with contents of the base maps to obtain a generalized idea of the extent of the range of a particular wildlife species. Following this initial overview to discern the generalized extent of the range of the species, the manager is concerned with detecting characteristics of the population(s) of animals within the range.

At this point the manager begins to concentrate his attention on the detail within the boundaries of the general range of animals he initially outlined. By studying the computer-generated type maps he will be able to draw bounds around areas having similar characteristics. The landscape and composition of the vegetation of the area within each unit delineated by the manager can be regarded as unique. When the manager has reconstituted the base maps on the basis of the ground cover classification, he has devised preliminary "habitat maps" similar to the specifications of Alexander (34). These maps then will become the guides for stratification in the ensuing population analyses.

Stratified data collection will allow the application of statistical tests to the parameters from the respective strata. These tests will enable biologists to identify differences or similarities in various wildlife populations. According to evaluations of the statistical test results biologists will be able to delineate geographic areas inhabited by similar populations of a given wildlife species. These areas will be termed management units. The wildlife resources within each unit will be administered according to appropriate management treatments deemed necessary to produce sustained yields of wildlife resources.

Furthermore, these units, in themselves, will become stratification guides for intensive studies designed to provide data input for population modeling. Wildlife managers then will be able to examine management alternatives with respect to any given set of circumstances influencing any given population of animals.

ACKNOWLEDGEMENTS

The authors wish to thank Mr. John Wells, Governor's Office of Information Services, personnel of the Earth Observations Division, NASA Johnson Space Center, Houston, Texas, and personnel of the Remote Sensing Center, Texas A&M University, College Station, for their technical advice.

REFERENCES

1. Winkler, C. H., 1915, The botany of Texas: Univ. of Texas Bull. 18. 27 p.

2. Tharp, B. D., 1926, Structure of Texas vegetation east of the 98th meridian: Univ. of Texas Bull. 2606. 97 p.

3. Cottle, H. J., 1931, Studies in the vegetation of Southwest Texas: Ecology 12:105-155.

4. Pessin, L. J., 1933, Forest associations on the uplands of the lower Gulf coastal plain: Ecology 14:1-14.

5. McBryde, J. B., 1933, The vegetation and habitat of the Carrizo sands: Ecol. Monogr. 3:247-297.

6. Dyksterhuis, E. J., 1946. The vegetation of the Fort Worth prairie: Ecol. Monogr. 16:1-29.

7. Gould, F. W., and Box, T. W., 1965, Grasses of the Texas coastal bend: Texas A&M Univ. Press, College Station, Tex. 186 p.

8. Davis, R. B., and Spicer, R. L., 1965, Status of the practice of brush control in the Rio Grande Plain: Texas Parks Wildl. Dept. Bull. No. 46. 40 p.

9. Tharp, B. C., 1952, Texas range grasses: Plant Res. Inst., Univ. of Texas Press, Austin, Tex. 125 p.

10. Gould, F. W., 1962, Texas Plants - a checklist and ecological summary: Texas Agric. Exp. Stn. Misc. Publ. 585, 112 p.

11. Kuchler, A. W., 1964, Potential natural vegetation of the conterminous United States: Am. Geogr. Soc. Spec. Publ. 36. 116 p. + map.

12. Johnson, P. L., ed., 1969, Remote sensing in ecology: Univ. of Georgia Press, Athens. 244 p.

13. Holz, R. K., ed., 1973, The surveillant science: remote sensing of the environment: Houghton Mifflin Co., Boston, Mass. 390 p.

14. MacConnell, W. P., and Garvin, L. E., 1956, Cover mapping a state from aerial photographs: Photogramm. Eng. 22:702-707.

15. Hay, C. M., 1974, Agricultural inventory techniques with orbital and high-altitude imagery: Photogramm. Eng. 40(11):1283-1293.

16. Cowardin, L. M., and Myers, V. I., 1974, Remote sensing and classification of wetland vegetation: J. Wildl. Manage. 28(2):308-314.

17. Carter, V., and Schubert, J., 1974, Coastal wetlands analysis from ERTS MSS digital data and field spectral measurements: Proc. 9th Int. Symp. on Remote Sensing of the Environ., Ann Arbor, Mich.

18. McKendrick, J. D., and Scorup, P. C., 1974, A super bird's eye view of Alaska: Agroborealis 6(1):26-30.

19. Joyce, A. T., 1974, Computer implemented land use classification with ERTS digital data during three seasons: NASA Lyndon B. Johnson Space Center Rep. 135. 19 p.

20. Phillips, T. L., ed., 1973, LARSYS Version 3 user's manual, volume 1-2: Purdue Res. Foun., West Lafayette, Ind.

21. Jones, C., 1974, Implementation of an advanced table look-up classifier for large area land-use classification: NASA Lyndon B. Johnson Space Center Rep. 15. 15 p.

22. Eppler, W. G., Helmke, C. A., and Evans, R. H., 1971, Table look-up approach to pattern recognition: Proc. 7th Symp. on Remote Sensing of Environment, Univ. of Michigan, Ann Arbor, 1415-1425.

23. Kuchler, A. W., 1967, Vegetation mapping: The Ronald Press Co., New York. 472 p.

24. Oosting, H. J., 1956, The study of plant communities: an introduction to plant ecology: W. H. Freeman and Co., San Francisco. 440 p.

25. Weaver, J. E., and Clements, F. E., 1938, Plant ecology: McGraw-Hill Book Co., Inc., New York. 601 p.

26. Haralick, R. M., 1972, Data processing at the University of Kansas: Proc. 4th Annu. Earth Resour. Program Rev., Houston, Texas.

27. DeVos, A., and Mosby, H. S., 1971, Habitat analysis and evaluation: Pages 135-172 in R. H. Giles, Jr., ed., Wildlife management techniques. 3rd ed. The Wildlife Society, Washington, D. C. 633 p.

28. Forbes, R. D., 1955, Forestry handbook: The Ronald Press Co., New York.

29. Avery, T. E., 1969, Forester's guide to aerial photo interpretation: U. S. Dept. of Agric. Handb. 308. 40 p.

30. Hahn, H. C., Jr., 1951, Vegetation inventory of Kerr Wildlife Management Area: Texas Game Fish Comm. P-R Proj. Rep., W-53-R, Job IV. 74 p. Multilith.

31. Haas, R. H., and McGuire, J. M., 1974, Evaluating remote sensing applications for land resource management: Phase II summary report: Texas A&M Univ. Remote Sensing Ctr., College Station, Tex. 20 p.

32. Anderson, J. R., Hardy, E. E., and Roach, J. T., 1972, A land-use classification system for use with remote sensor data: U. S. Geol. Surv. Circ. 671. 15 p.

33. Swain, P. H., 1973, Pattern recognition: a basis for remote sensing data analysis: Purdue Univ. Lab. for Applications of Remote Sensing LARS Info. Note 11572. 41 p.

34. Alexander, M. M., 1959, The habitat map: a basis for wildlife management: New York Fish Game J. 6(1):102-113.

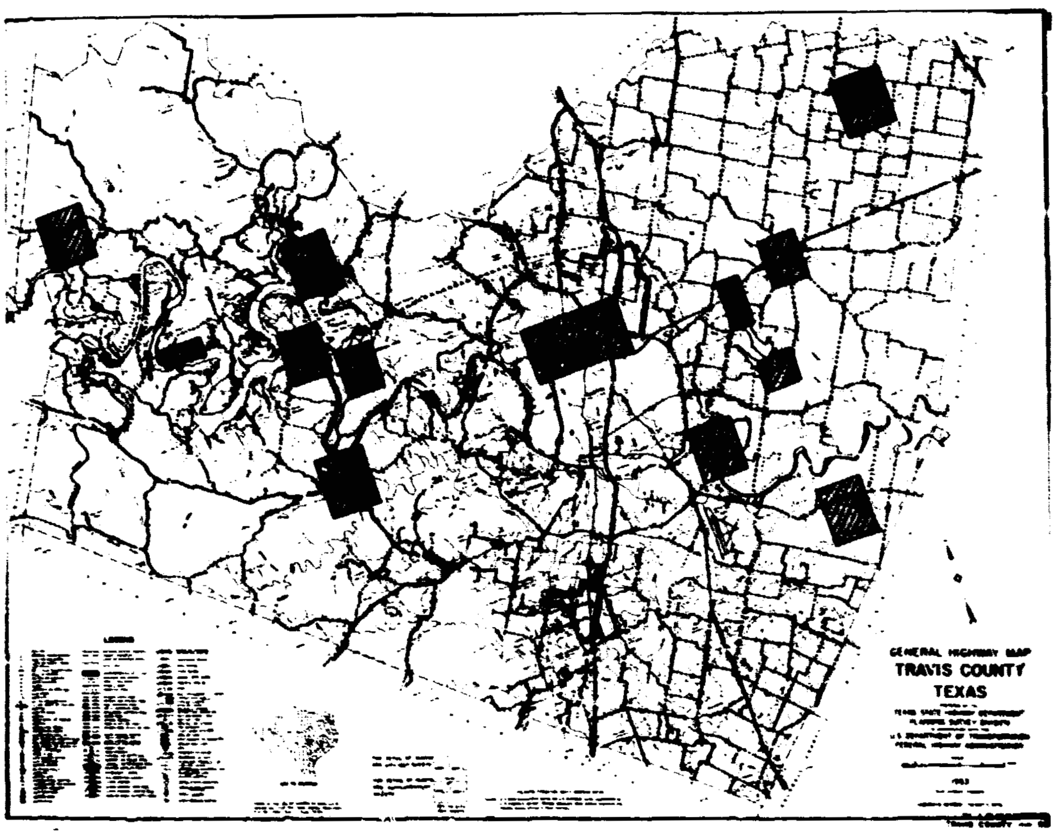


Figure 1. Distribution of cluster sites in Travis County, Texas

LEGEND

Cedar (ashe juniper) Woodland

Cedar-Liveoak Woodland

Cedar-Liveoak-Mesquite/Bluestem composite (indicates a mosaic pattern of highly interspersed, but individually distinct plant associations composed of these dominants)

Native Grassland

Tame Grassland (agriculturally induced; bermuda, etc.)

Agriculture (plowed or disced cropland and fields, grazed cover crops)

Elm-Hackberry-Mesquite Mixed Woodland

Urban, residentially built up areas, roads

Urban, commercially built up areas

Water

Figure 2. Classification map of eastern Travis County, portrayed at every fifth pixel

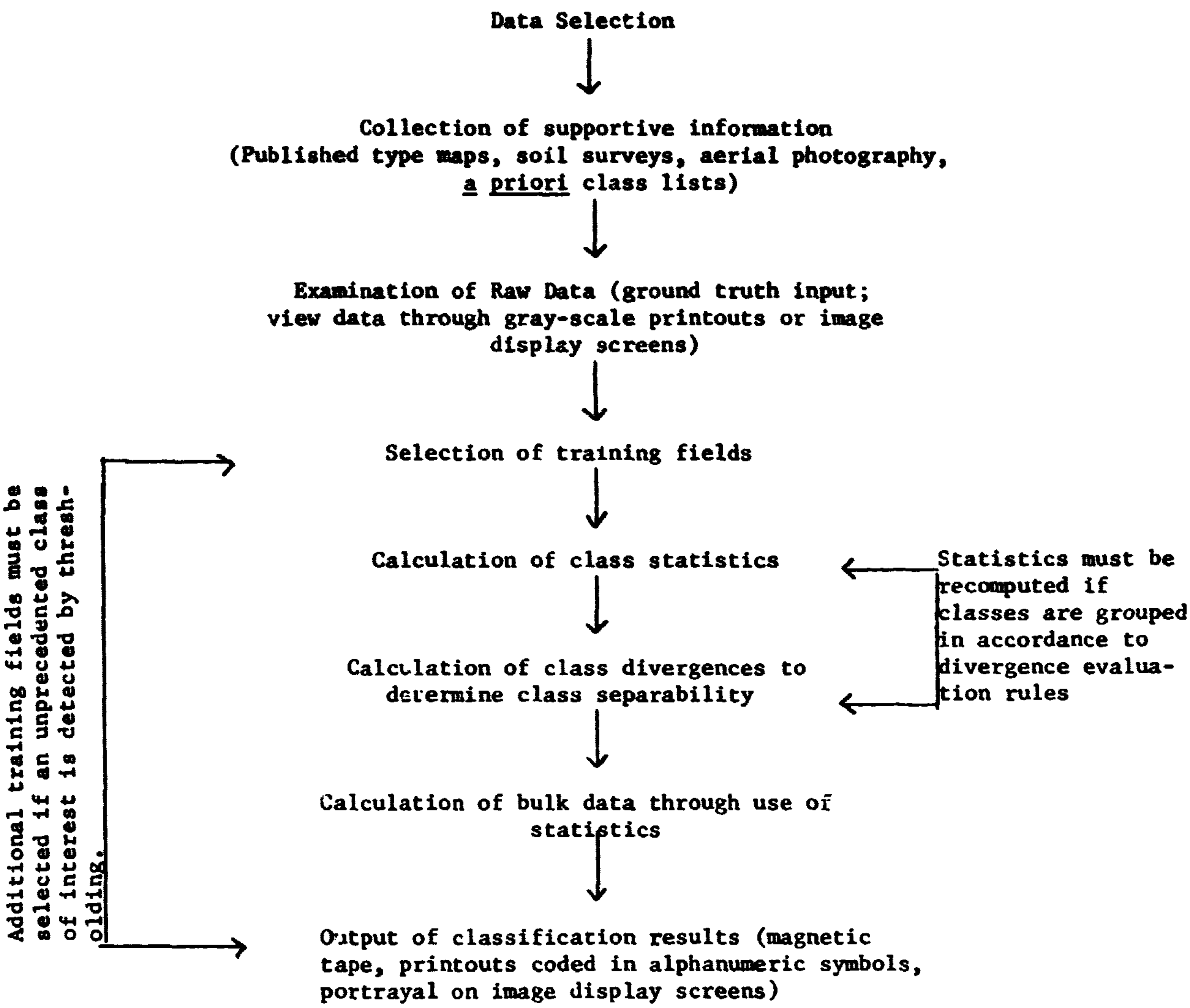


Figure 3. Flow Diagram of Procedures for Computer-assisted Analyses

Frame No.: ______________________

Cluster No.: ______________________

Date: ______________________

County: ______________________

General Topography of Cluster Site ______________________

____

Supplemental Information: ______________________

____

Designation of Classes on Cluster Map

Cluster Symbols:	1	2	3	4	5	6	7	8
Physiognomic ID.:								
Floristic Dominants:								

Figure 4. Training Field Record

APPENDIX A

LARSYS ANALYSIS PROCESSORS

From Phillips, T. L., ed. 1973. LARSYS Version 3 User's Manual, Volume 2. Purdue Research Foundation, West Lafayette, Indiana

IDPRINT — Prints listing of the identification record for multispectral image storage tape runs; gives information on date data acquired, observation identification number, orbit number, cloud cover, and time of day of overflight.

PICTUREPRINT — Produces alphanumeric pictorial printouts of the data for each channel that is specified; used to check data quality and select subsets of data to be used; alphanumeric symbols are shown in gray scale tones.

CLUSTER — Classifies individual data points into a predefined number of clusters: user must estimate the number of clusters (or classes) to be produced; guides analyst to features to be identified for use in developing training statistics.

STATISTICS — Calculates statistics of subsets of data values (mean, standard deviation, a covariance matrix, and a correlation matrix) for the channels specified; resulting statistics file contains statistical descriptions of the specified training classes.

SEPARABILITY — Uses class statistics to calculate measurements of how well the individual classes may be distinguished from one another, or the degree of "separability" between the classes.

CLASSIFYPOINTS — Classifies multispectral data on a point-by-point basis; uses class means and covariance matrices (computed in STATISTICS) and the data from each point to be classified to calculate the probability that the point belongs to each of the training classes; stores output on disc file or magnetic tape.

PRINTRESULTS — Provides variety of printed outputs describing the classification results produced by CLASSIFYPOINTS; provides researcher with a flexible capacity to display the results of a classification in the form of a map image and/or tabular outputs.

APPENDIX B

PHYSIOGNOMIC CLASSES

Cropland	Includes cultivated, fallow or human altered locations used for the purpose of producing food and/or fiber for either man or domestic animals.
Grasses	Herbs (grasses, forbs, and grasslike plants) dominant; woody vegetation lacking or nearly so (≤ 5 percent woody canopy coverage).
Savannah	Individual woody plants > 9 ft. tall widely scattered throughout grass (6-10 percent woody plant canopy coverage).
Groves	Clusters, or groves of woody plants widely scattered throughout grass (6-10 percent woody canopy cover).
Parks	Woody plants ≥ 9 ft. tall generally dominant (11-30 percent canopy cover) with continuous grass or forbs.
Brush	Woody plants < 9 ft. tall dominant, occurring in generally evenly spaced stands (> 10 percent canopy cover).
Woods	Woody plants 9-30 ft. tall growing evenly spaced or nearly so (> 30 percent canopy cover); midstory usually lacking.
Forest	
Mature	Deciduous or evergreen trees dominant; mostly > 30 ft. tall, (> 30 percent canopy cover); midstory apparent except in managed monoculture.
Young	Deciduous or evergreen trees ≤ 30 feet tall ($>$ 30 percent canopy cover); midstory usually absent; potential to form mature forests.
Marsh	Emergent herbaceous plants dominant in inundated areas; woody vegetation lacking or nearly so ($\leq$ 15 percent woody canopy coverage).
Brush Swamp	Woody plants < 9 ft. tall (> 15 percent canopy coverage occurring on inundated or almost constantly inundated sites).
Parkland Swamp	Woody plants > 30 ft. tall generally dominant (15-30 percent total woody canopy cover) occurring on inundated or almost constantly inundated sites.
Wooded Swamp	Woody plants mostly 9-30 ft. tall occurring on inundated or almost constantly inundated sites (> 15 percent canopy coverage).
Forested Swamp	
Mature	Trees mostly > 30 ft. tall occurring on inundated or almost constantly inundated sites (> 30 percent canopy coverage).
Young	Trees mostly ≤ 30 ft. tall occurring on inundated or almost constantly inundated sites ($>$ 30 percent canopy coverage); potential to form "mature forested swamp."
Water	Streams, lakes, ponds, estuaries, lagoons, flooded oxbows and water treatment facilities.

Inert Materials

Spoil	Bare soil deposited from dredging operations in marsh, swamp, estuaries, lagoons, or streams.
Dunes	Unvegetated sand mounds or hills.
Urban	Includes roads, industrial and suburban developments.

Other Vegetated areas which portray physiognomy difficult to define or categorize and which could produce significant classification error if labeled separately; includes those groups that do not appear to fit above criteria.

E-2

AN OVERVIEW OF THE DEVELOPMENT OF REMOTE SENSING TECHNIQUES FOR THE SCREWWORM ERADICATION PROGRAM

Charles M. Barnes, NASA/Johnson Space Center
and
Frank C. Forsberg, Lockheed Electronics Company, Inc., Houston

N76-17488

ABSTRACT

This paper reports the current status of remote sensing techniques developed for the screwworm eradication program of the Mexican-American Screwworm Eradication Commission. A review of the type of data and equipment used in the program is presented. Future applications of remote sensing techniques are considered.

INTRODUCTION

The screwworm is the larval stage of the fly *Cochliomyia hominivorax* (Coquerel). It is distinctive in that the larvae feed only on living tissue, the population density is relatively small, and the female fly mates only once in her lifetime. The latter traits make the screwworm fly vulnerable to the sterile male technique for its eradication (see ref. 1). The screwworm fly lays its eggs in open wounds, and the resulting larvae can kill or cripple an animal within a few days. One of its favorite wounds is in the navel of newborn animals (refs. 1 and 2); therefore, little wildlife exists where screwworms are present. In fact, before the eradication program, a major chore of southern ranchers was to treat screwworm-infested animals.*

In the United States, the screwworm caused an economic loss of over 100 million dollars annually before the eradication program began. The latest estimates indicate that the losses without a screwworm program could exceed 200 million dollars a year (refs. 3 and 4).

Although there are no overwintering screwworm fly populations in the United States, the insect survives in Mexico; and as the weather warms, the flies spread northward into the United States (ref. 5).

To reduce the impact of this overwintering population and to prevent reestablishment of the screwworm in the United States, a

*An excellent survey of the developments leading to the sterile-male techniques developed by the U.S. Department of Agriculture for the eradication of screwworms is given in "The Eradication of the Screwworm Fly" by E. F. Knipling, *Scientific American*, 203:54-61, 1960. A more detailed review is presented in "Eradication of the Screwworm Fly" by A. H. Baumhover, *JAMA*, 196:240-248, 1966.

barrier of sterile flies was established (shown in fig. 1). This barrier extends to 480 km deep and stretches along the U.S. and Mexican border from the Pacific coast to the Gulf of Mexico. Up to two hundred million flies per week are dropped in the barrier and in isolated outbreak areas in the southwestern United States. Maintenance of the barrier costs 12.5 million dollars annually but does not totally protect the United States (ref. 6).

The United States and Mexico have agreed on a cooperative program to eradicate screwworms in northern Mexico, moving the barrier to the Isthmus of Tehuantepec, where the barrier would be only 177 km wide. The cost of maintaining this new barrier has been estimated at 1.5 million dollars, less than one-eighth of the cost of the present barrier.

REVIEW OF THE TECHNICAL PROBLEM

The screwworm fly in most infested areas has a low population density. For effective eradication, the local population must be overwhelmed with flies sterilized using radioactive cobalt and cesium gamma rays. These sterile flies are distributed from the factory to regional staging zones where they are delivered by aircraft in accordance to a daily flight schedule planned by the area epidemiologist. The flightlines are based on field case reports, personal experience, knowledge of spraying operations, and estimates of the effects of weather.

The environment is extremely important to the eradication program. If it is too cold, the screwworms die; if too hot and dry, they desiccate. For maximum efficiency in inundating an area with sterile flies, it is best to choose a time in which the adult population has already been reduced by weather factors and the new pupae have not yet emerged (ref. 3). If a system can be devised for predicting these areas, enormous savings are possible through the efficient use of flies. The present cost of producing and distributing these sterile flies is $0.001 each. Since 500 million flies will be dropped each week, even a 10 percent decrease in flies liberated represents savings of 2.5 million dollars annually.

To efficiently define the local environment for release of flies, it is necessary to have good support from either ground weather stations or from some other source.

In Mexico, a limited network of meteorological stations exists and even more limited communications connect them. Further, the terrain is complicated by extremely varying topography. To supplement the existing weather data from Mexico, additional climatological stations must be activated at an estimated annual cost of several million dollars, or satellites or aircraft can be utilized to collect environmental data.

In 1970, the Health Applications group of the Lyndon B. Johnson Space Center (JSC), National Aeronautics and Space Administration (NASA), decided to plan an experiment which would determine the feasibility of remote sensing to assist the Mexican-American screwworm commission in defining weather parameters of importance to screwworm eradication. A detailed study was made of various options and it was decided to suggest

use of the Improved TIROS Operational Satellite (ITOS) (fig. 2) as a basic source of satellite data. A project plan was then developed for implementing a system that could provide planning information on where flies should or should not be dropped (fig. 3) based on weather parameters.

TECHNICAL REQUIREMENTS TO ACHIEVE PROJECT OBJECTIVE

The basic objective of the project was to determine the specific earth environment conducive to the growth of the screwworm fly and to develop remote sensing techniques useful to an eradication program. For the development of a remote sensing system, the environmental factors affecting the screwworm had to be quantified, a capability of processing ITOS data had to be developed, the relationship of satellite data to screwworm populations had to be demonstrated, and a processing system capable of daily production of environmental data for all of Mexico had to be developed.

Quantifying Environmental Factors Affecting the Screwworm

The screwworm has been extensively studied by agricultural scientists for more than 30 years. They had noted that a relationship seemed to exist between weather and the screwworm population. This relationship, however, had never been sufficiently demonstrated or quantified; therefore, an extensive literature search was undertaken (ref. 7).

The cycle of the screwworm (fig. 4) was studied to determine the environmental factors (fig. 5) that seem to affect population growth. They are the same as those that affect other insects and plants. The problem was to determine the effect of various aspects of the environment on each phase of the screwworm life cycle and on the total life cycle. The most rewarding investigation dealing with the overall effect of weather on the total life cycle was a 6-year retrospective study of available meteorological data (ref. 7). A typical plot of data showing the number of screwworm cases and the weather is shown in figure 6.

The weather conditions for each phase of the life cycle were plotted against the screwworm's life cycle; the modeling study resulted in the definition of a weather potential for screwworm growth (ref. 8). The weather conditions for each phase of the life cycle were plotted against the resulting growth per insect generation (fig. 7). Many factors, other than weather (e.g., availability of host animals, predators, and presence of an eradication program), may modify the population growth per generation. It becomes apparent from the study, however, that the potential growth of populations can be determined for various conditions.

Establishing Satellite Data Processing Capability

ITOS satellite radiometric data were obtained from the National Oceanic and Atmospheric Administration (NOAA) receiving station at Wallops Island, Virginia. The analog tape was mailed directly to JSC

where it was displayed on a Visacorder for selecting the desired areas. The useful portion was duplicated, and 5 days of data stored at JSC on one reel. Data collected were archived, and a selected number of days in this time period were digitized, calibrated, and made into color-coded images.

NOAA digitized tapes were not used since, at the time the project began, digital tapes were not routinely available and digital data would have occupied too large a portion of a storage facility when weighed against the potential use for a specific day of data.

Although ITOS has several radiometers, only the very-high-resolution radiometer (VHRR) is being used. The VHRR is a two-channel scanning radiometer sensitive to energy in the visible band and from 10.5μ to 12.5μ in the infrared band. The size of the picture element (pixel) is approximately 0.9 km at the subsatellite point and degrades to about 1.45 km at the edge of its scan. The satellite observes each point on Earth twice a day and has a scan width of about 1,900 km. The NOAA satellite contains redundant VHRR sensors that are operated in tandem, 180° out of phase with each other. The visible data from one sensor are time-multiplexed with the infrared data from the second and transmitted continuously as one data channel. The signal may be received from anywhere in the world with the proper receiver and antenna. However, the signal is weak and the reception requirements are stringent.

Registration of the data was one of the more difficult technical problems to overcome. A computer software program for registering data over an area of several hundred miles was written for the development program, and it was found to be accurate within one pixel. Although this registration program was satisfactory for a test and development phase, another program had to be developed for the daily routine registration of data obtained on all of Mexico daily for the production system. Before registering data over an entire country, the analog signals should be nonlinearly digitized, either through a software resampling program or by use of a hardware function generator as was done in the production system. If nonlinear digitization is not done, the registration program will be very inefficient in computer processing time.

Techniques were also developed for correcting the data for atmospheric attenuation and surface emissivity. The atmospheric attenuation correction was derived by modifying and adding to basic correction programs developed by the National Environmental Satellite Service (NOAA). From a series of tests, it appeared that the results were satisfactory provided that one remained in the same air mass. The importance of emissivity correction can be determined from figure 8. Emissivity correction is difficult and is still under study. A promising new method may shortly be reported as a result of studies in Mexico and in the southwestern United States.

A problem in developing a useful system for recording environmental factors from satellites is that the satellite records radiometric temperatures and all surface meteorological reports are made as air temperature. A strong correlation of radiometric temperature to air temperature, however, was found (see fig. 9). Moreover, air temperature was not necessarily needed at a certain time of day but rather an

average for the day or averaged over several days. By using multiple regression techniques for conversion from radiometric to daily air temperature, satisfactory accuracies have been obtained.

Relationship of Satellite Data to Screwworm Population

To demonstrate the relationship of screwworm activity with satellite data, two test sites were established: one near McAllen, Texas, and the other near Fortín de las Flores, Veracruz, Mexico. The Texas test site has flat terrain, relatively clear days and nights, an abundance of ground truth, and the presence of an ongoing eradication program. The Fortín test site is almost completely opposite in character with its rugged terrain, extensive cloudy periods, lack of an eradication program, and limited ground truth (except that which could be established locally by project personnel). The results achieved in each test site were different, as one might expect, and are, therefore, considered separately.

The McAllen test site was established before activation of the international agreement between NASA and the Comisión Nacional del Espacio Exterior (CONEE), the Mexican space agency, to participate in the screwworm program. Because of the high-quality data obtained during early studies, work in this test site was continued and expanded to cover additional areas in Texas for the duration of the developmental phase of the project. This test site was operated as part of a cooperative arrangement with scientists from the U.S. Department of Agriculture (USDA) experiment station in Weslaco, Texas. In exchange for ground truth data, NASA provided processed satellite imagery. Records of screwworm activity throughout South Texas were correlated with surface and satellite observations.

The Mexican test site has an approximate radius of 150 km. This area lies on the southeastern edge of the Mexican highlands where the ground descends precipitously towards the coastal plains. Elevation varies from near sea level to above 2,000 m. In the Mexican test site, an office was established and equipped with a radio for daily communications with JSC. Establishing and operating the Mexican test site presented some problems. First, as a developing country, Mexico has protective tariffs that strictly control all equipment entering and leaving the country. Second, it has stringent work permit regulations to protect jobs for Mexican nationals. Third, it has strong labor rules and a comprehensive social security system for which industry is taxed according to complex laws. Last, administrative practices in Mexico are more deliberate than is customary in the United States. The approach taken to solve these problems was to subcontract a Mexican company responsible for hiring personnel, supplying equipment and office space, and meeting the legal obligations.

Local inspectors hired by the subcontractor were trained by the USDA screwworm research staff at Mission, Texas. Their duties included baiting traps, collecting and sorting flies, visiting ranchers for screwworm case reports, and making presentations to local ranch associations.

Forty fly traps were placed in selected areas having rather well-defined roadways for ease of servicing. Weekly visits were made to the traps and selected ranches. Larval samples were collected during these visits for screwworm verification. A Mexican scientist, either from CONEE or from the joint screwworm commission, served as test site director with a U.S. supported scientist as the backup.

Approximately 20 meteorological stations were established in the test area to measure the variation in local climate. Sites for the stations largely reflected areas that were easy to service and yet representative of the general area. Weather parameters measured included daily maximum/minimum air temperature, daily total precipitation, continuous air temperature, continuous relative humidity, soil moisture (once a week), and soil temperature (once a week).

The results obtained from the two test sites varied widely. Figure 10 shows the correlation of the satellite radiometric surface temperature to air temperature in the McAllen test site at shelter height at the time of satellite passage. Data obtained by satellites at varying orbits over the Texas test area were used in this figure, and the best-fit regression line is shown. The root-mean-square (rms) estimate of error was 1.9° C.

Figure 11 shows a few of the data sets obtained from NOAA-3 as it passed over the Mexican test site and the best-fit regression line. The rms estimate of error was 2.53° C. As is evident, data from this test site were less useful than the data from the McAllen test area for developing algorithms, probably because of map accuracy problems. When the same geographic position of a small meteorological station was plotted on three different Mexican maps, the resultant latitudes and longitudes were different for all three. The radiometric data show considerable scatter, which might be expected with uncertainty in the precise location of the ground meteorological station. When combined with the possible registration error (2 km), sizeable position errors can be produced.

For example, consider the meteorological station at Los Carriles, which is located in an area of rapid change in altitude and terrain. An uncertainty of 2 minutes in either the latitude or the longitude can result in a positional error of 1.4 km or 1.5 resolution elements (pixels) in the satellite data. This is not a large degree of uncertainty considering the conflicting information contained in maps of this area. The computer registration error on the order of 2 resolution elements would result in a possible location error of 3.5 elements in the radiometric map. Figure 12 shows a computer printout of the area around this station for August 28, 1974, and a circle of 3.5 resolution elements in radius. As can be seen from the accompanying temperature analysis, this radius of possible location can result in a variation of 10° C in temperature range.

The Screwworm Eradication Data System (SEDS)

Two contractors were assigned to support the screwworm project; the Lockheed Electronics Company, Inc., was responsible for developing basic

research and development techniques and the Aeronutronic Ford Company for designing the hardware and software and for integrating all into the daily production system, known as SEDS. Dr. Charles Barnes of the Bioengineering Systems Division was responsible for overall systems development as related to the screwworm eradication program and was the technical monitor of the basic research, established system requirements. Mr. Robert Spaulding of NASA/Ground Data Systems Division was the technical monitor for the development of SEDS. As Lockheed developed basic algorithms, programmers or engineers from Aeronutronic Ford implemented them into SEDS. SEDS is now operational; however, additional capabilities, such as emissivity corrections, still need to be added. Some coefficients also need to be refined on the basis of analyses conducted over many days. Even so, it appears that the accuracy of SEDS at this time is within 2.5° for estimating mean daily air temperature averaged over 4 days. These accuracies are expected to improve as coefficients are refined and the emissivity correction is added.

Figures 13 through 16 show representative products of the SEDS. Figure 13, the product designed for use by epidemiologists, shows areas in which conditions are favorable for screwworm growth. This product is prepared from data presented in Figures 14 through 16, all of which are produced from temperature data. In addition, it incorporates the Crop Moisture Index for Mexico, prepared at JSC using programs of the U.S. Department of Agriculture.

The data that SEDS is now producing daily must be evaluated by the developers and potential users. Field tests will assist in refinement of the algorithms and increase accuracies before actual operational evaluations can be made. This evaluation will be completed in 1976, at which time the daily processing of data is expected to resume if the current evaluation proves favorable.

THE FUTURE OUTLOOK

Many who are familiar with the results of the work achieved by this small group believe that there are many other applications which could use daily radiometric temperatures over extended periods. Indeed, in any application in which the response variables are temperature dependent, the techniques developed for screwworm eradication should be useful. These may include frost warnings, crop yield predictions, or plans for shrimp harvesting or for the eradication or control of other insects. Certainly the developments described in this paper are at a very early stage. With the approaching launch of more sophisticated meteorological satellites having improved radiometers and moisture sensors, new avenues of remote sensing may be opening. The potential for using and correlating data from several different kinds of sensors could create the synergism needed to solve some of the most difficult remote sensing problems.

ACKNOWLEDGMENTS

A list of people who have contributed their special talents to the growth of a work of this magnitude is endless; however, we would like to give special recognition to a few. Mr. Russ Koffler, NESS/NOAA, gave much needed aid to all phases of the project from its conception to the present. Mr. Paul Nixon, ARS/USDA, gave special aid in the collection of ground truth. Dr. Richard Davis has contributed through his in-depth reviews of the project.

The development of the daily production system, SEDS, was the result of a concentrated effort by many. In particular, however, Bob Spaulding, Charles Parker, and Dave Young are among the NASA scientists who made significant contributions. The excellent work performed by Norman Hines, Paul Audel, Hal Halpin, Steve Jorgenson, James and Sharon Boatright, Jack Biddle, and Earl Miller of Aeronutronic Ford in designing and integrating a production system must be acknowledged. From the Lockheed Electronics Company, the list of persons to be acknowledged must include Dale Phinney for developing the basic algorithms, Everett Thompson for satellite processing techniques, Gerald Arp for his emissivity work, and Morgan Gibson for collecting, analyzing, and reporting screwworm data, and Lorrain Giddings who worked numerous detailed problems, and Alberto Broce who directed the Veracruz test site effort.

Our many Mexican friends have also contributed in both a scientific way and in moral support during times of political stress. First are Engineers Raul Higuera and Sergio Padilla of the Mexican Space Commission, Aguilar Anguiano of the Mexican Meteorological Service, and Dr. Marco A. Villaseñor, Director of the Mexican-American Screwworm Eradication Commission.

We sincerely appreciate the support of NASA management in providing funds for this series of experiments.

REFERENCES

1. Knipling, E. F. "The Eradication of the Screwworm Fly." *Scientific American*, 203:54-61, 1960.

2. Baumhover, A. H. "Eradication of the Screwworm Fly." JAMA, 196:240-248, 1966.

3. Phinney, D. E.; and Gibson, M. S. "Weather and the Screwworm." *Weekly Weather and Crop Bulletin*, 62:14-15, 1975.

4. Kryder, H. Personal communication. July 1974.

5. Facts about the Screwworm Barrier Program. United States Department of Agriculture - Agricultural Research Service, ARS 91-64-1, Oct. 1969.

6. Proposal for a USAF Civic Action Program in Latin America. DCS/Plans and Operations, Headquarters USAF, June 1967.

7. Gibson, M. S.; and Phinney, D. E. Selected Parameters Influencing the Growth and Survival of *Cochliomyion hominivorax* (Coquerel). LEC-4090, 1974.

8. Phinney, D. E. The Influence of Meteorological Conditions on the Growth and Development of Screwworm Populations. LEC-5987, 1975.

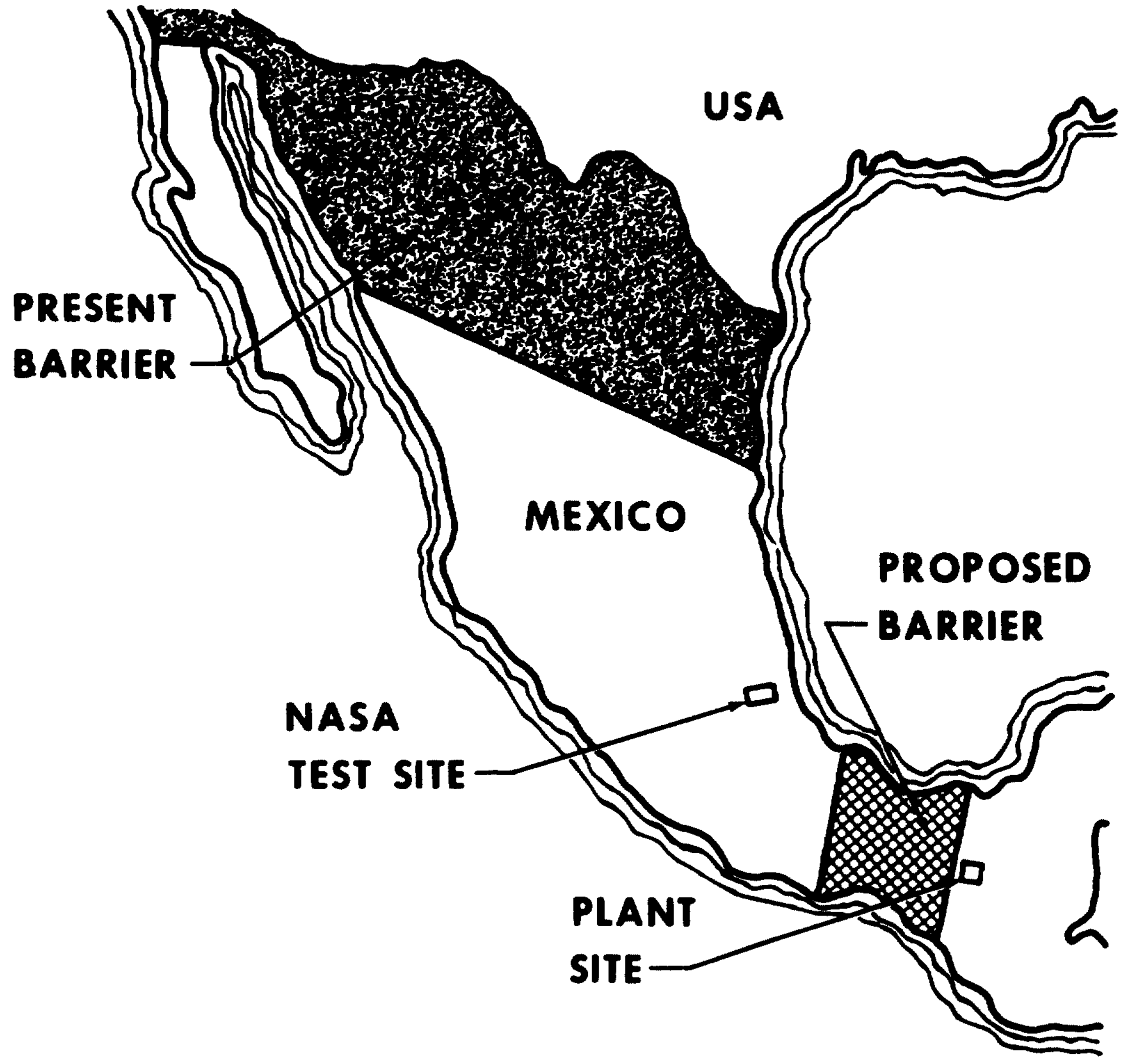


Figure 1. – Present and proposed screwworm fly barrier.

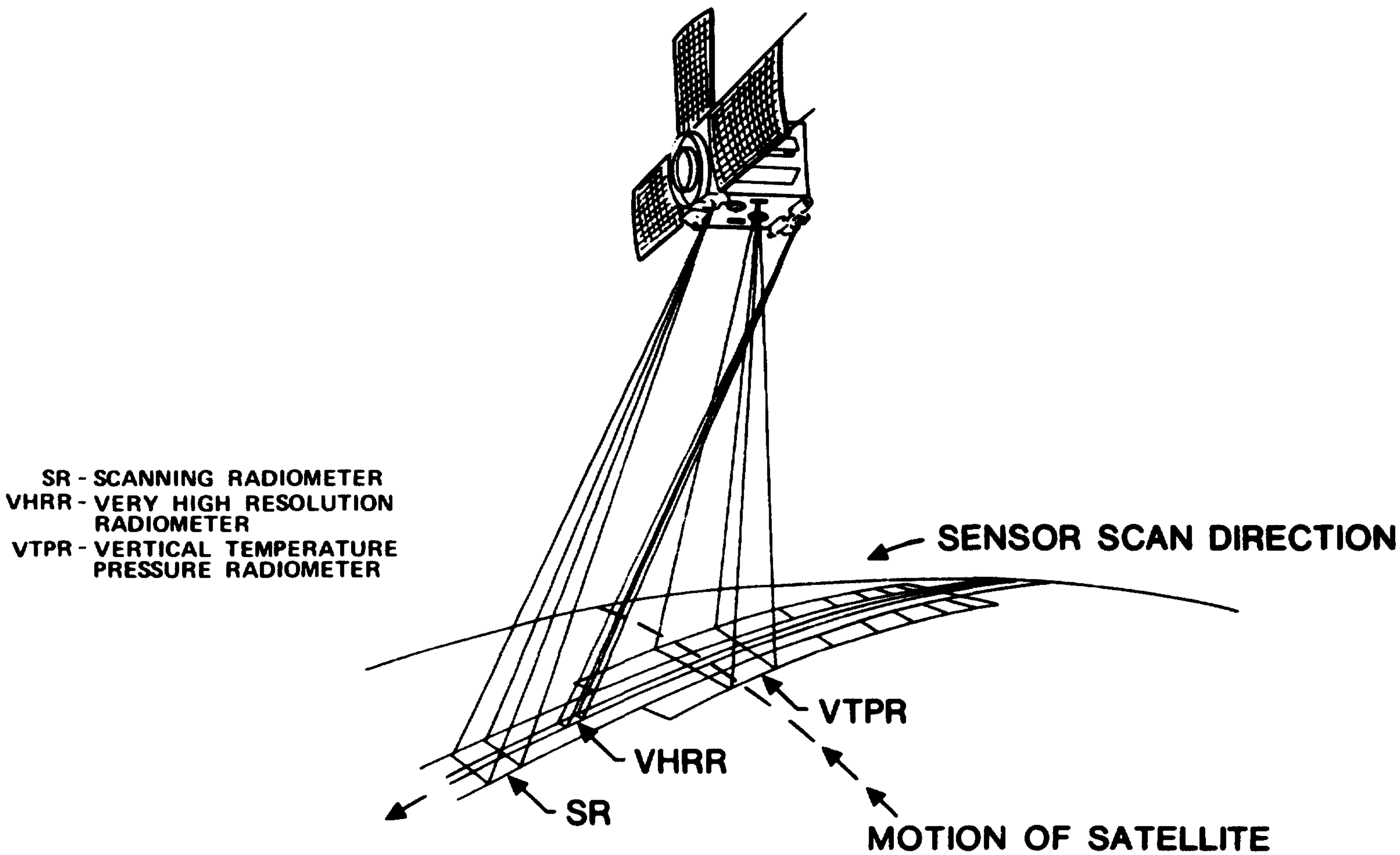


Figure 2. — The Improved TIROS Operational Satellite utilized in the screwworm eradication project.

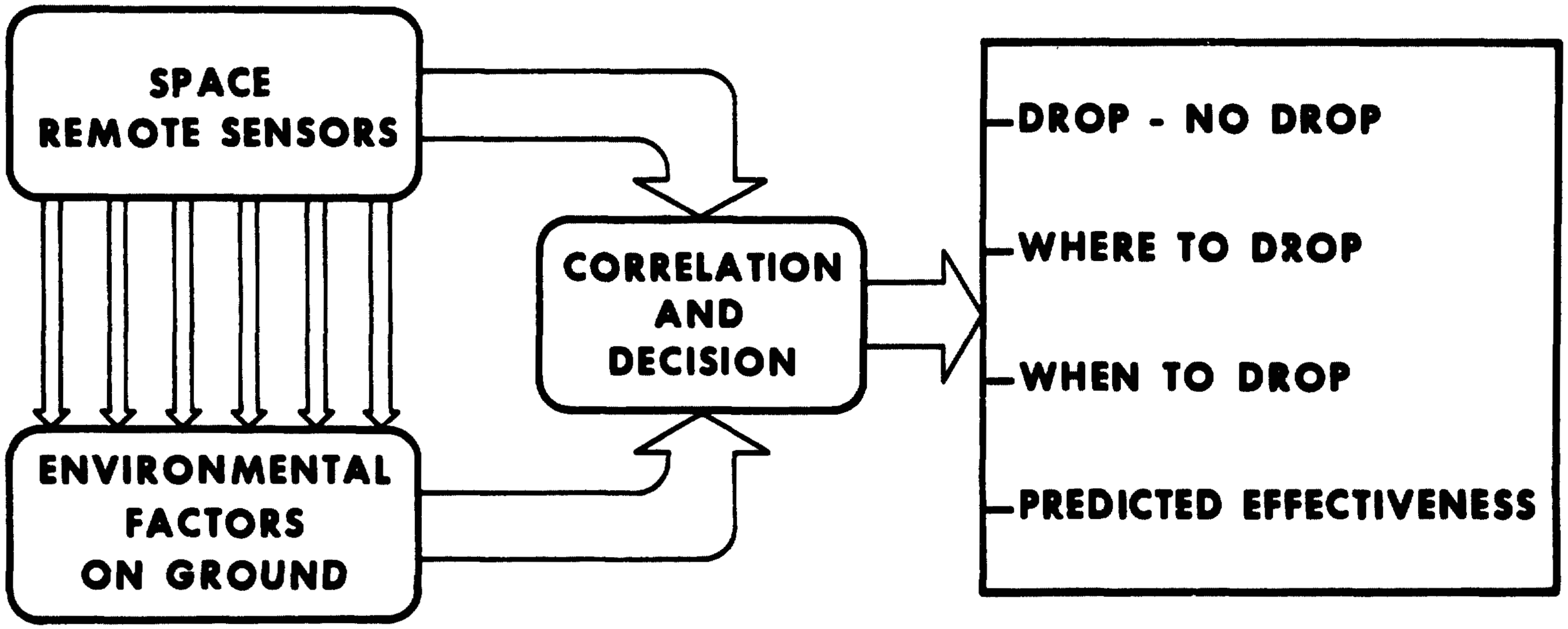


Figure 3. — System for providing planning information of where male sterile flies should or should not be dropped.

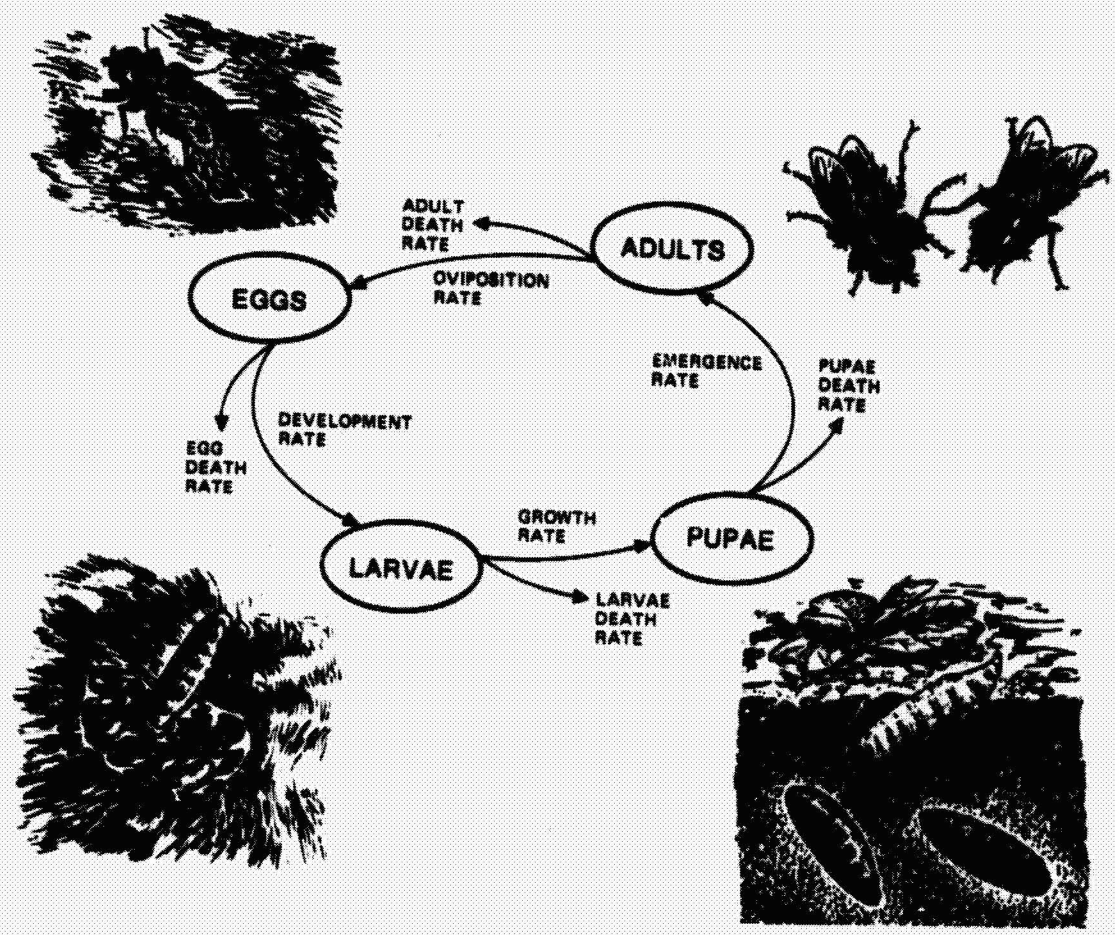


Figure 4. — Screwworm life cycle.

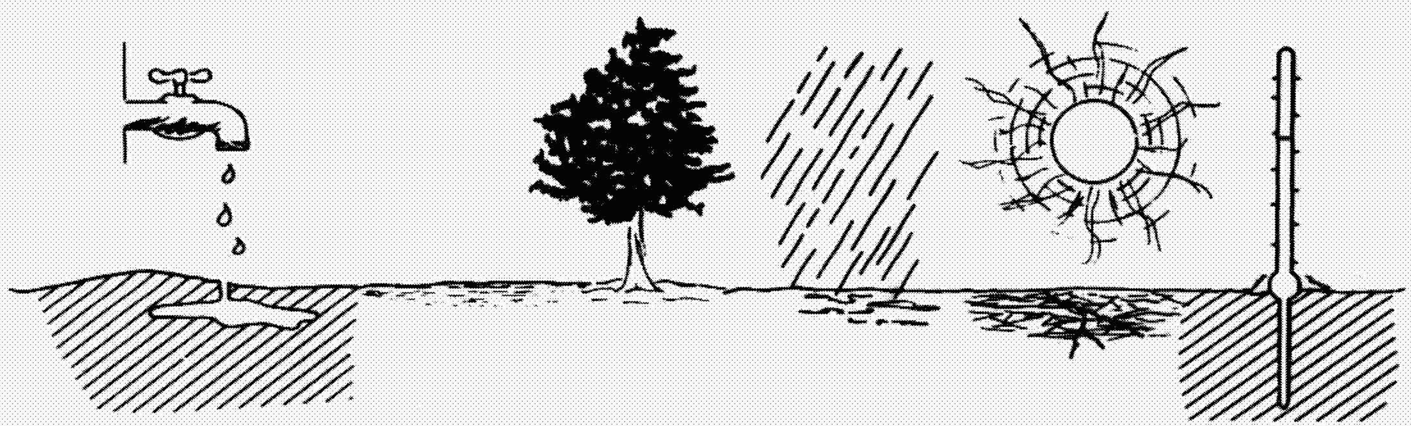


Figure 5. – Environmental factors affecting the life cycle of pupating insects.

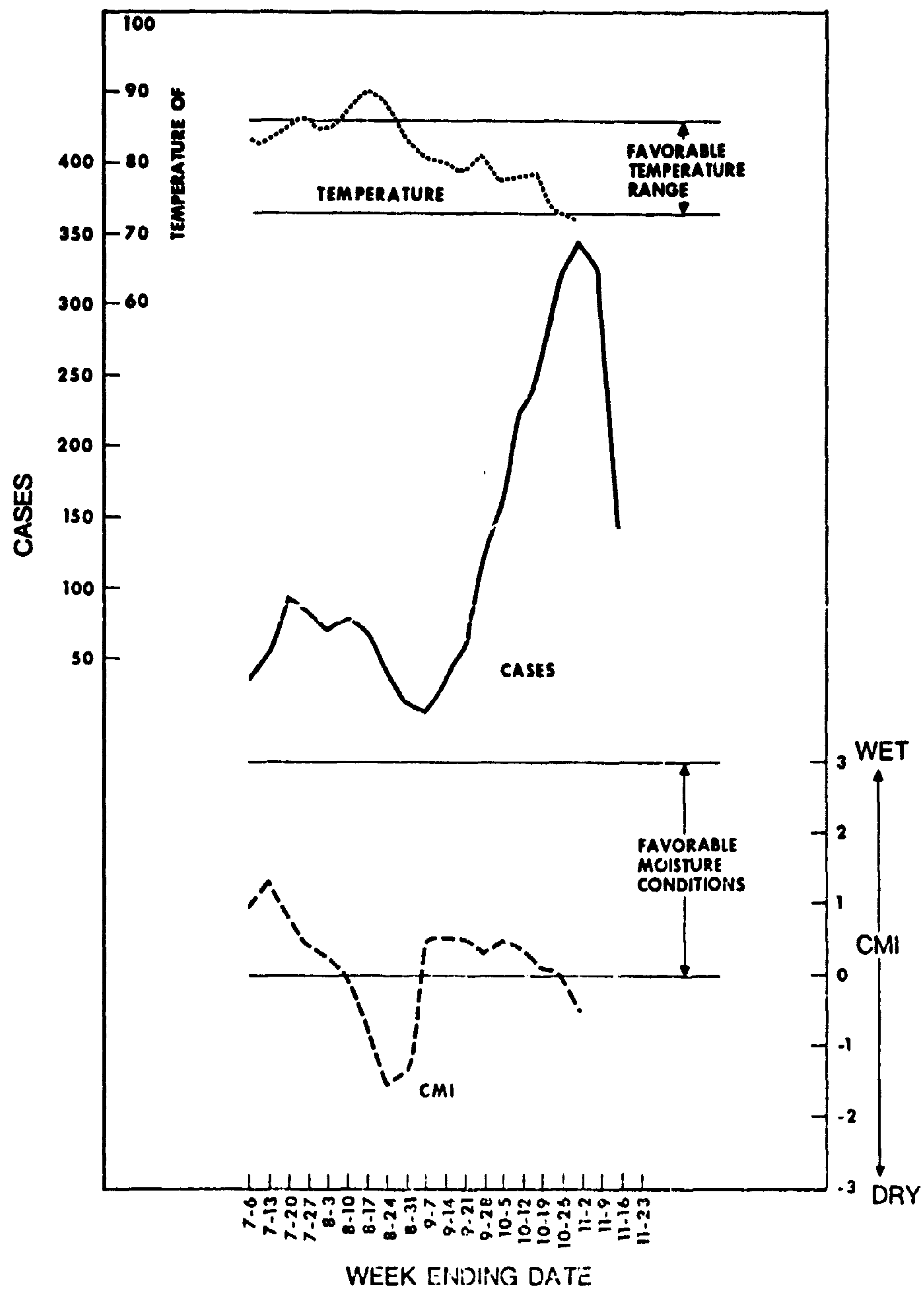


Figure 6. – Plot of data showing the number of screwworm cases and the weather.

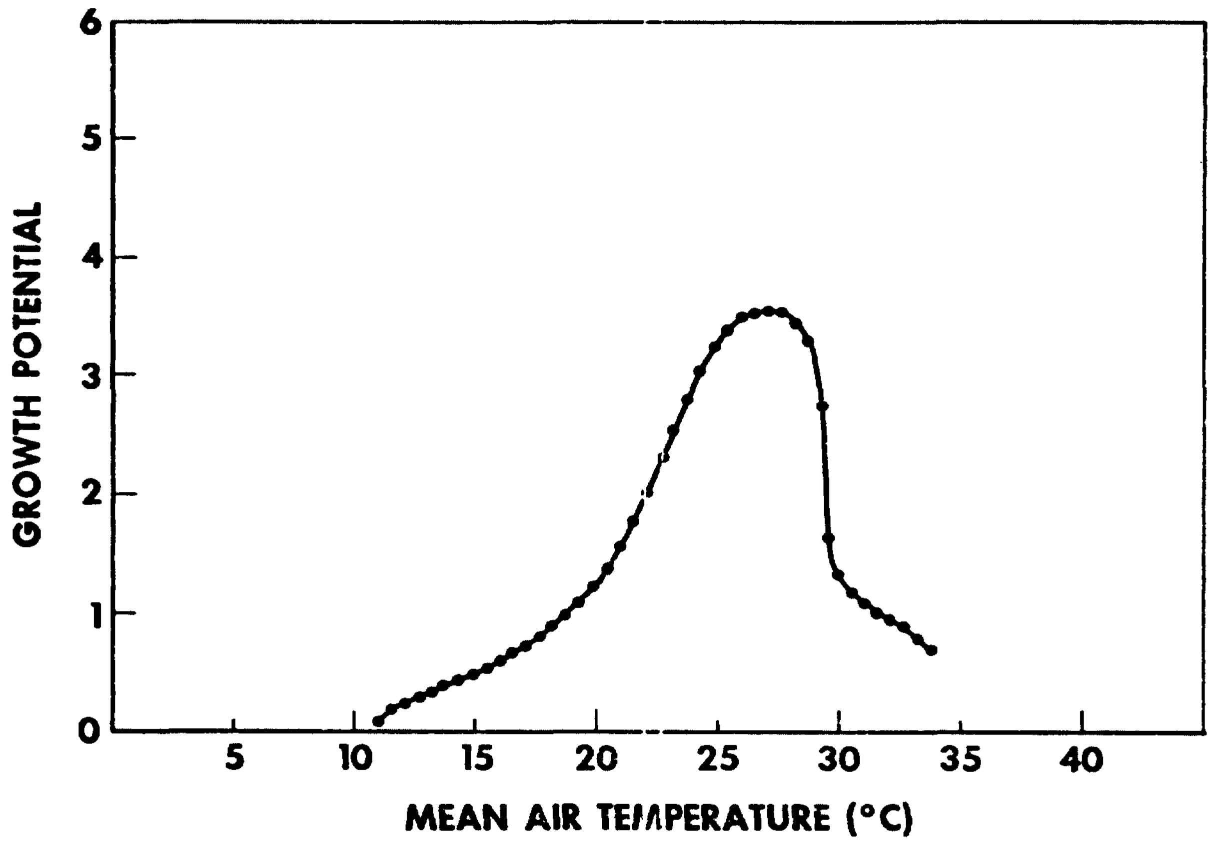


Figure 7. — Relationship between mean air temperature and growth per generation.

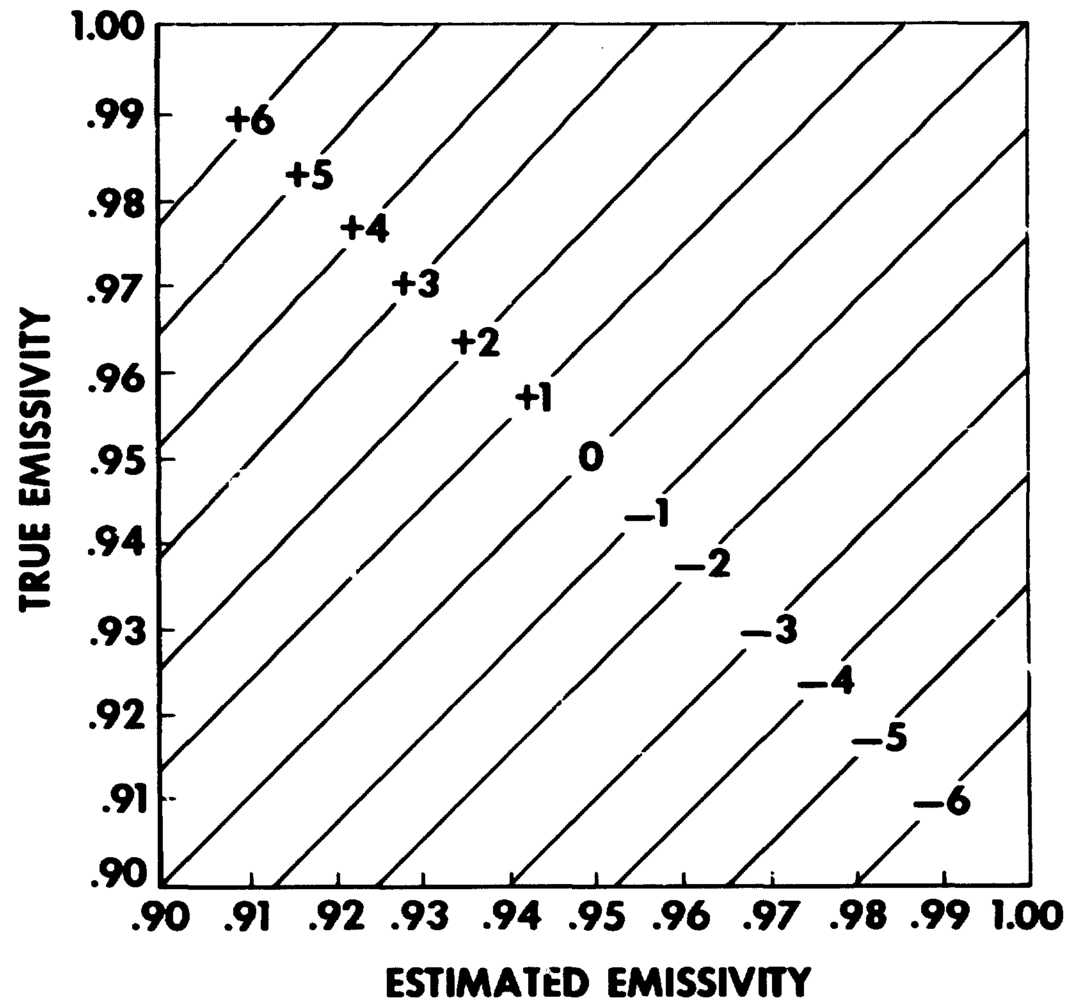


Figure 8. — Temperature error (°C) associated with an incorrect assumption of emissivity at 300° K.

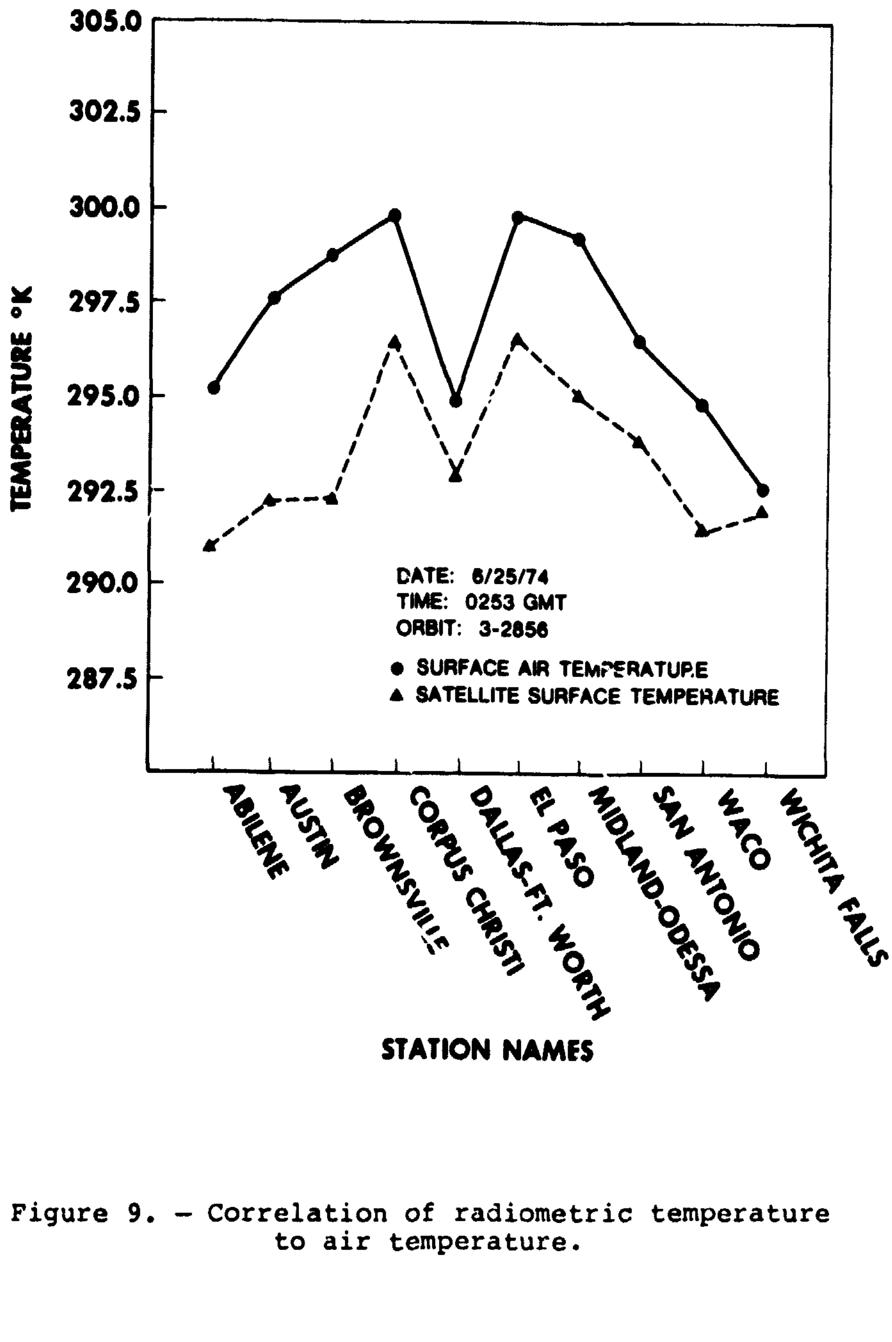


Figure 9. – Correlation of radiometric temperature to air temperature.

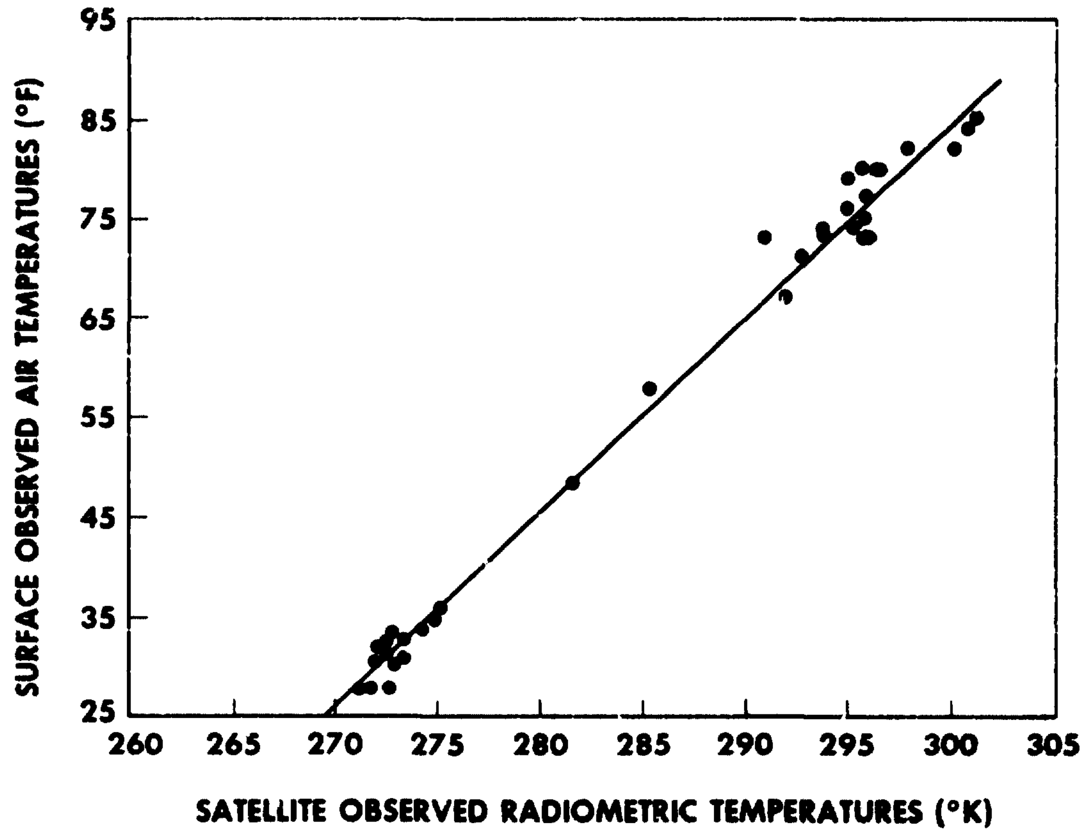


Figure 10. — Correlation of radiometric temperature to air temperature in the Texas test area.

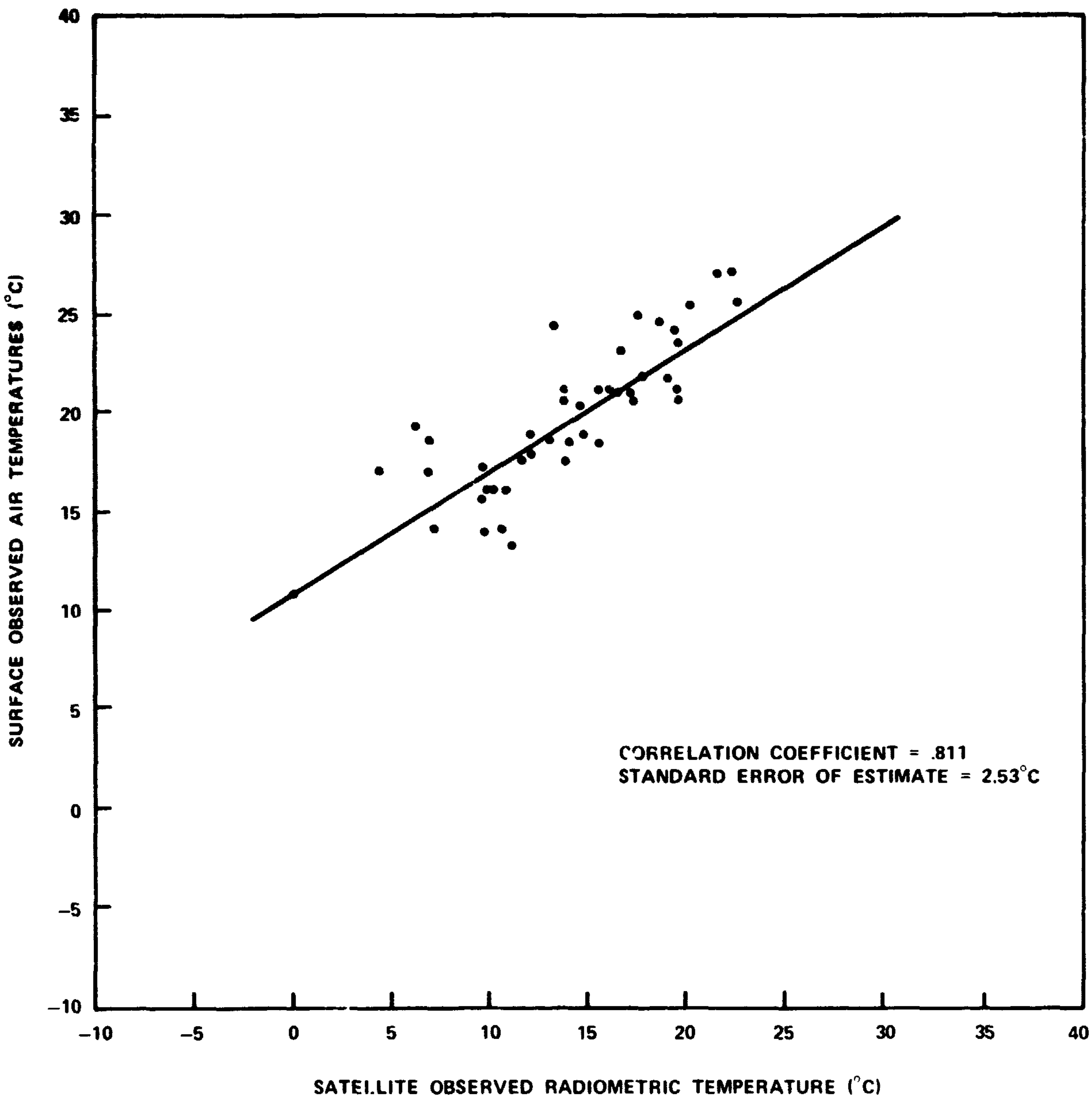


Figure 11. – Comparison of satellite data with surface temperature in the Fortín de las Flores test site.

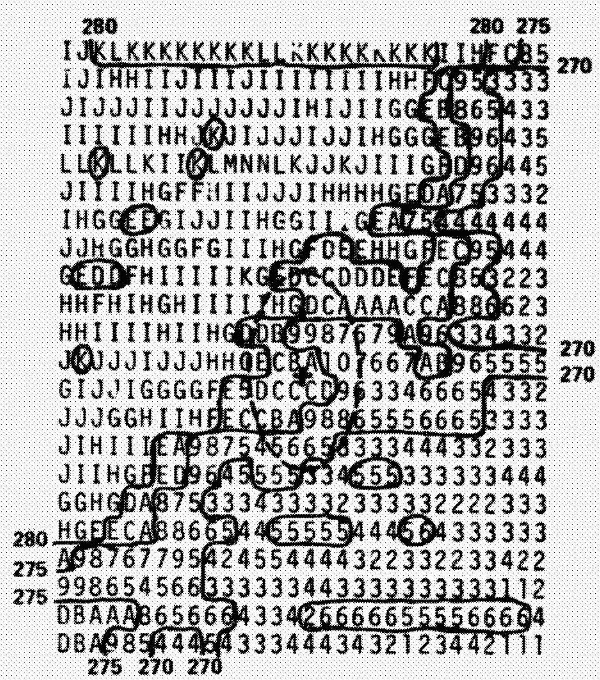
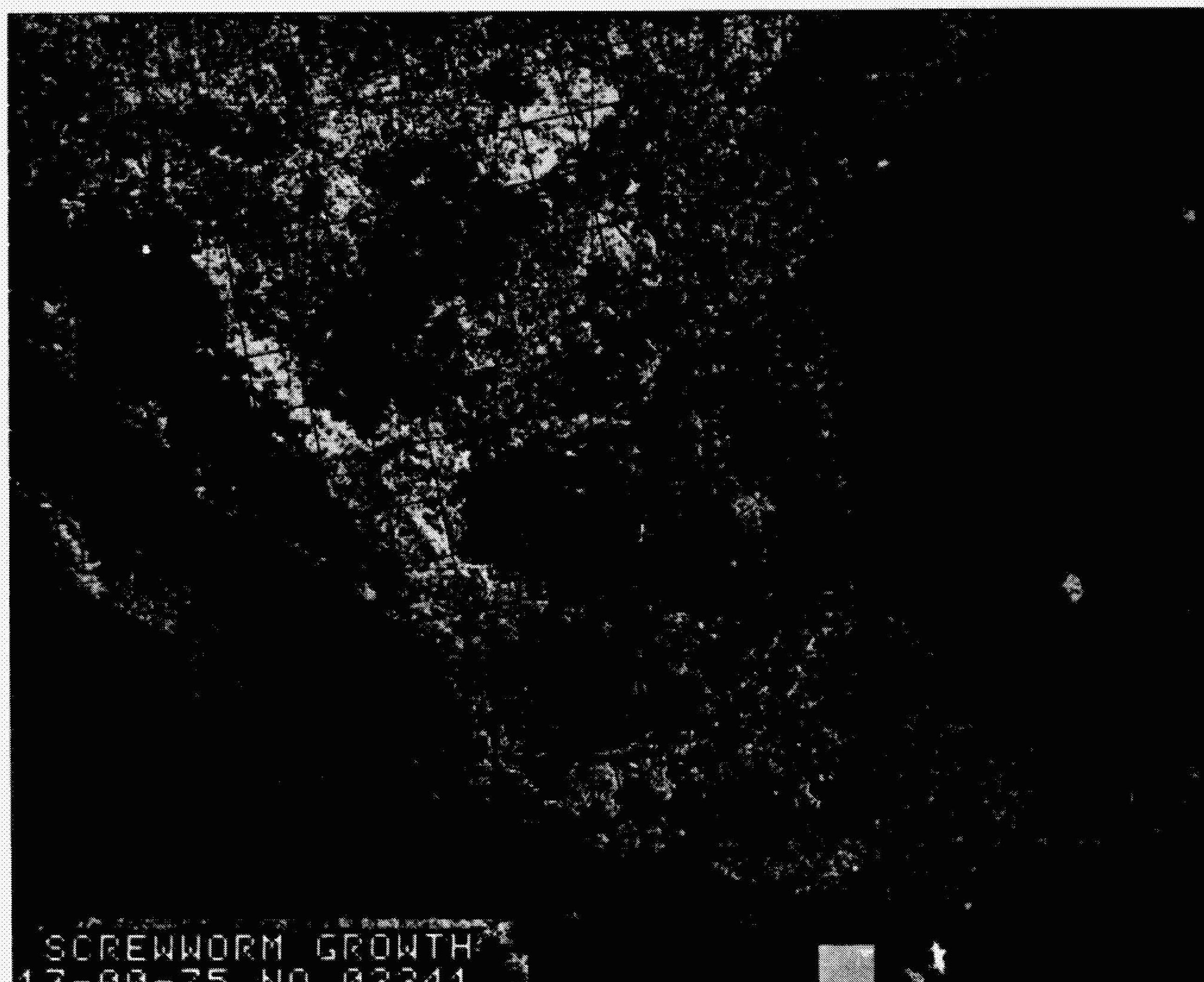
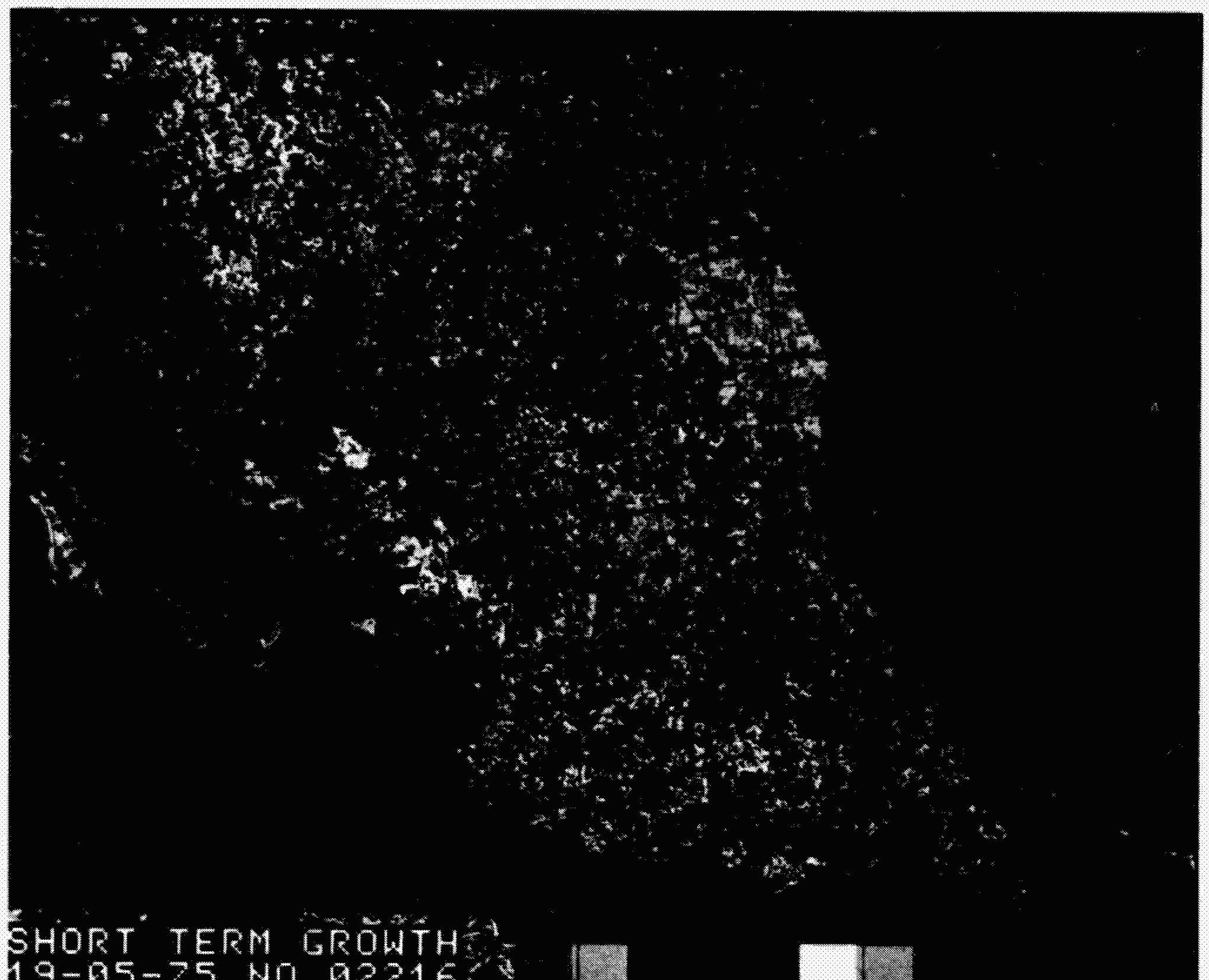


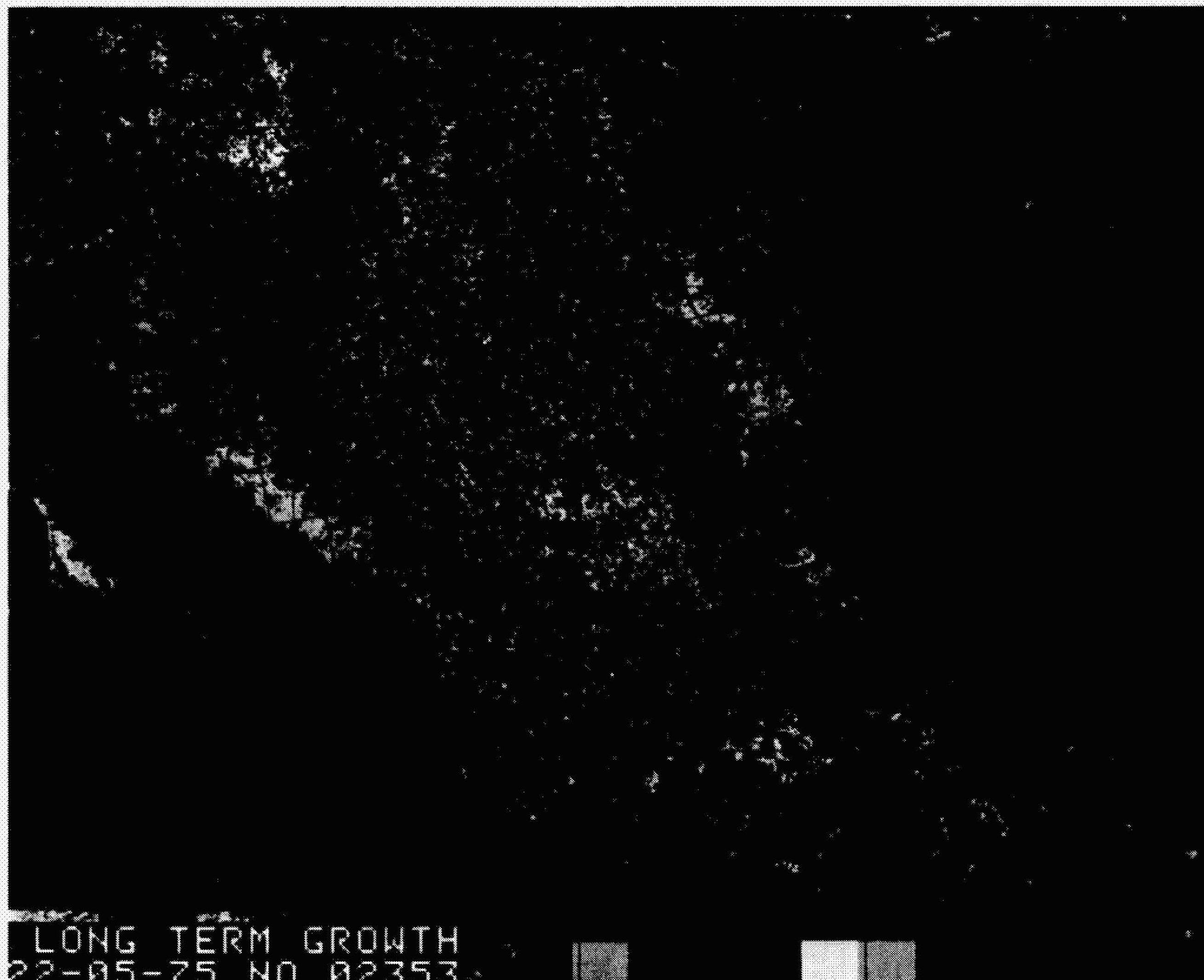
Figure 12. — Los Carriles with possible location error and temperature analysis, °K.



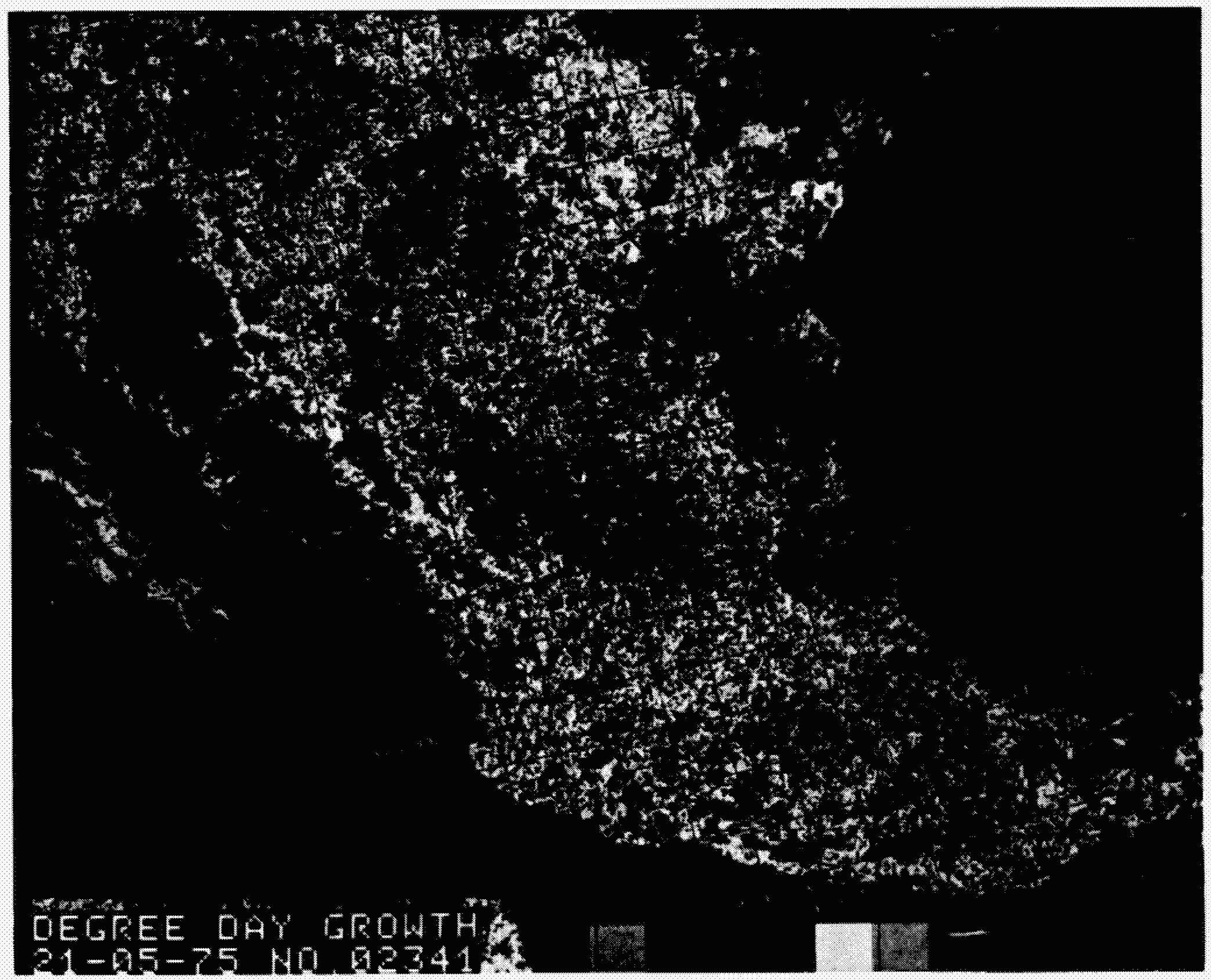
Screwworm Growth — Figure 13. — This image depicts the combined effects of temperature and soil moisture on screwworm populations. The potential for screwworm outbreaks as a function of weather increases as the colors shown move from blue through red.



Short Term Growth – Figure 14. – The effect of short term variation in mean air temperature on the growth of screwworm populations is shown in this display. The particular impact of weather shown here is that of air temperature on the activity and survival of adult flies. It is color coded in the same manner as figure 13.



Long Term Growth — Figure 15. — This image shows the effect of temperature on the pupae phase of the screw-worm fly. A long term mean air temperature is calculated, and the correlated pupae survival and development are shown in color. It is color coded in the same manner as figure 13.



Degree Day Growth — Figure 16. — The length of the pupae phase is a function of temperature and is calculated through a modified degree day summation. The potential for screwworm development is shown here as a function of the length of the pupae phase. It is color coded in the same manner as figure 13.

THE RATIONALE FOR ATTEMPTING TO DEFINE SALT MARSH MOSQUITO-BREEDING AREAS IN GALVESTON COUNTY BY REMOTE SENSING THE ASSOCIATED VEGETATION E-3

By Gerald K. Arp, Lockheed Electronics Co., Houston, Texas

ABSTRACT

N76-17489

This presentation is concerned with the rationale for attempting to define salt marsh mosquito breeding areas in Galveston County. It includes a botanical survey of the marsh plant communities, their relationship to flooding, and their exposure to salt water. Particular emphasis is given to *Distichlis spicata*, a widespread marsh grass. Evidence suggests that breeding areas of *Aedes sollicitans* are associated with *Distichlis* and that both species respond to similar ecological conditions in the salt marsh. Aspects of the remote sensing of the *Distichlis* are considered.

INTRODUCTION

Salt marsh mosquitoes *(Aedes sollicitans)* are prevalent in large numbers along the Atlantic and Gulf coasts of the United States. The species is a strong flier and a savage biter; the mosquito is a great nuisance and a potential transmitter of disease in populated coastal areas (ref. 1). Wherever *Aedes sollicitans* is a problem, effective mosquito control has been difficult because the species breeds in coastal salt marshes and then flies into populated areas (refs. 1, 2, 3).

The salt marsh biome provides one of the richest natural habitats in nature and one of the most important food resources for man. For example, 28 percent of the total fish catch in the United States comes from the Gulf of Mexico. Of these 28 percent, not less than 97.5 percent is composed of estuarine species, oysters, and crustaceans which spend some portion of their lives in estuaries and bays associated with the coastal salt marshes (ref. 4). Any imbalance by insecticide poisoning or habitat destruction for mosquito control may ruin the salt marsh as a food source for the associated fish and could devastate the American fish industry.

Researchers and mosquito control personnel have frequently noted that an association exists between the distribution of certain salt marsh grasses, *Distichlis spicata* and *Spartina patens*, and the breeding areas of *Aedes sollicitans* (refs. 3, 5, 6, 7, 8, 9, and 10).

A project for developing remote sensing techniques to support local or regional mosquito control efforts was initiated in the Galveston area in late 1973 and continues. A test site was selected by personnel from the Galveston County Mosquito Control District and the Department of Preventive Medicine and Community Health University of Texas Medical Branch, Galveston in a salt marsh near the town of

Hitchcock in south Galveston County to analyze salt marsh plant composition, to define the sources of local salt marsh mosquitoes, and to attempt the use of remote sensing for effectively delimiting the specific areas of mosquito production for efficient mosquito control without damaging the important associated salt marsh.

The project was developed for the Health Applications Office of the National Aeronautics and Space Administration (NASA) led by Dr. Charles W. Barnes, Chief, and directed by Dr. F. T. Satalowich, Deputy Manager. Analyses of mosquito/breeding areas are being conducted by Dr. Warren F. Pippin, whereas the author is concerned with the composition of the marsh vegetation. Uses of various remote sensing techniques for determining the distribution of the plants is in progress and will be reported later. In this communication, we will concern ourselves with the rationale for attempting to define mosquito breeding areas in South Galveston County and we will analyze the basic composition of the salt marsh vegetation for use in remote sensing the associated salt marsh mosquito breeding areas.

METHODS

To develop an understanding of the marsh itself, background reference material was studied at length (refs. 11, 12, 13). Plants were identified by using standard botanical keys (refs. 14 and 15). Extensive botanical surveys were conducted on the ground and from boats to define the extent and identity of all important marsh components of the test site. Aerial surveys were completed with aid of several NASA and Galveston County helicopter missions. Aerial photographs were made by the author by using a Nikon 35-mm camera at various altitudes from 0.91 m (3 ft.) to 3,048 m (10,000 ft.). Film types included color and color IR film. Other data were obtained by two NASA overflights on November 21, 1973, and April 2, 1974, which included the use of black-and white infrared film and 24-band multispectral scanners. Additional data were provided by the Earth Resources Technology Satellite when possible.

RESULTS AND DISCUSSION

Relationship of Mosquitoes to Salt Marsh Plants

Precise mosquito-breeding areas must be defined for an efficient mosquito control program. Mosquitoes themselves are much too small and ephemeral to be censused directly, but the vegetation growing in their breeding areas is a permanent and recognizable entity. Because the mapping of mosquito-breeding areas is done indirectly, it is necessary to justify the validity of this approach to understand why mosquito-breeding areas can be mapped by the remote sensing of the associated vegetation.

Breeding patterns of the salt marsh mosquito are governed by the occurrence of intermittent flooding after a long, dry period of

days, weeks, or months. The mosquito eggs may be laid in almost any moist place in the marsh and its associated grassy areas. The species seems to be little affected by variations in water salinity. Broods arise in 5 to 30 days, depending on the temperature. The emergent adults mate, and the females lay most of their eggs in the debris at the base of the vegetation just above the receding waterline (refs. 2, 9, 10, 16, 17). There is no time for development in the duration of a single daily tidal action. The species must choose an area which holds water long enough for development (3 to 8 days), but not long enough to sustain predators (as in a permanent pool).

Several things are important here. First, the area cannot remain constantly flooded, or no eggs will be laid. Second, the area must be flooded long enough for a brood to complete development. Third, an area must be moist long enough for the eggs to be laid as the water recedes and dry long enough for the eggs to develop.

The salt marsh mosquito is not host specific to any species of plant, in the sense that it requires some plant species to help complete its development. This fact is borne out by the wide choice of reported breeding areas, from swimming pool and oil well effluents to salt marshes (refs. 18, 19, 20).

In the Galveston County salt marsh, the primary breeding areas lie above the weekly and daily high-tide zones. They include those regions that are flooded by heavy rains or storm tides and that retain the flood water for a few days, before the water drains away into the sea. Salt marshes frequently develop *Aedes* breeding grounds because the ground relief is very gradual, the soil is usually saturated, and the vegetation is dense enough to resist the flow of water, creating, in effect, a dam. As pointed out in reference 21, this dam retards the quick dispersal of flood waters that are otherwise unable to escape by draining into the saturated soil.

If the tidal action of an area, the height of the normal flood waters, and the topography are known, then the region of mosquito breeding can be theoretically and strictly defined. All of these predictable, measurable aspects are obtainable only on uniform beaches and marshes. In the natural marsh, anomalies abound, including the pocketing effect that inlets create, the dampering effect found on hidden or protected coves, and the dune patterning effect on tidal action. Additionally, the presence of variable vegetation types affects the rate and volume of tidal movement and flooding. The distribution of salt marsh vegetation critically reflects the soil and water conditions in a typical salt marsh. This same vegetation also reflects any anomalies in the marsh soil and water composition created by inlets, bayous, etc. (ref. 7). Further, the vegetation will respond in a predictable and appropriate manner to subsidence, dredging, road building, or grazing. The vegetation is a living record of marsh ecology, both past and present. Thus, a census of the vegetation provides a real picture of marsh conditions.

Based on the literature previously cited and on preliminary investigations by Dr. Pippin in the Galveston County mosquito test site, evidence suggests that *Aedes sollicitans* breeding occurs primarily in the *Distichlis spicata* association. Although there is no host specific correlation between the salt marsh mosquito and salt

marsh plants, the tidal conditions that produce a stratification of vegetation may also serve to delineate mosquito-breeding areas. This is possible because the intermittent tidal-flooding situation conducive to production of *Aedes sollicitans* is also conducive to the establishment and growth of *Distichlis spicata*.

The vegetation is a more practical indicator of conditions in the marsh than is the measurement of environmental and physical parameters (ref. 7). Thus, the vegetation is a permanent, responsive, and recognizable indicator of mosquito breeding and other marsh conditions (refs. 22 and 23). In the author's opinion, vegetation is the easiest, most accurate factor to census and map large areas for mosquito control or to monitor marsh conditions.

SUMMARY OF MARSH VEGETATION

The salt marsh is a very harsh habitat for plants, primarily because of the constant presence of salt water. Marsh species must tolerate salt spray, saline wet soil, and occasional immersion by fresh and/or salt water. Because few plant species have any tolerance to these conditions, diversity of species is very restricted. Among those species which are tolerant to these conditions, the degree of tolerance to variations in salinity and flood patterns is different (ref. 11). Consequently, in a marsh there is a separation of plant species into essentially pure growths of single species in response to the variations in salinity and flood patterns.

Table I illustrates the comparative positions of the important species associations found in normal portions of the test site in south Galveston County, and table II provides a simple key to each association. The position of each association is related to land elevation and water salinity. Land elevation alone creates the salinity gradient. Fresh water enters on the upslope and surface sides via rain, flooding, and percolation of water from inland out toward the sea. This water movement leaches the sea salts and soil nutrients down and toward the sea. Salt water enters from the seaside (lower side), and it too percolates through the soil. Tidal activity, winds, and storms push salt water onto land for varying periods of time and at varying depths throughout the marsh. A dynamic equilibrium results between fresh water and salt water and between flooded lands and higher lands. It is the distribution of this dynamic equilibrium which decides the distribution of salt marsh grasses. The grasses are tolerant to specific degrees of salinity and flooding and are thus confined to the particular marsh sites which they can tolerate.

Spartina alterniflora resides in those areas of the marsh that are frequently flooded by salt water and remain wet and very saline. This species resides along the muddy estuary margins and sits about 7.5 cm (3 in.) above the normal daily high-tide mark. The roots always remain in saline sodden mud, whereas the aerial portions and crown receive periodic inundation by salt water for periods of several weeks during each winter. During the summer, however, prevailing offshore winds allow for the drying necessary for growth.

Associated with *Spartina alterniflora* is *Batis maritima*. It grows in situations nearly identical to *Spartina alterniflora*, but is not as widely established in this particular marsh. As a zone, the *Spartina alterniflora* community may cover hundreds of square yards. Much of the area surrounding *Spartina alterniflora* and *Batis maritima* is devoid of all vegetation and consists only of flats.

On the higher, or uphill, side of the *Spartina alterniflora* and *Batis maritima* district, the *Distichlis spicata* association develops. It is also well adapted to highly saline water and long periods of inundation. However, it must reside in higher ground because of its shorter stature which does not allow it to compete with *Spartina alterniflora*. Associated with the widespread mat-forming *Distichlis spicata* is *Salicornia virginica*. This perennial *Salicornia* is fairly common and widely distributed among the *Distichlis*, but it is not evident most of the year because of the density of *Distichlis* stands. In the spring, however, the *Salicornia* does evidence itself for a few weeks. It is from this district that most *Aedes sollicitans* appear to be produced in Galveston County. This grassy community may cover hundreds of acres along the shoreline, and the association may mix with *Spartina patens*.

Spartina patens grows with and above *Distichlis spicata*. This *Spartina* can stand conditions similar to the *Distichlis*. Both species withstand flooding, prolonged inundation, and salinity, but *Spartina patens* seems less able to withstand the depths of water occasionally encountered by the *Distichlis*. *Spartina patens* therefore resides on higher ground. However, this apparent elevation may be due in part to the tussock type growth of *Spartina patens*. In the test site this grass forms only small mixed associations of a few square yards each. However, in other marshes, this grass is very important and is therefore treated as a separate association.

The salt flat community is found on muddy flats above those districts frequented by *Distichlis spicata* and *Spartina patens*. The flats are also found throughout the *Spartina spartinae* association and may actually form a subcommunity within the *Spartina spartinae* association. The salt flat association derives its name from the presence of expanses of unvegetated saline clay soil. Around the edges of these areas, mounds of *Salicornia utahensis* and *Monanthochloe littoralis* grow. The annual *Salicornia bigelovii* forms pure stands in the center of the mud flats during the spring of each year. Flooding soon kills out the *Salicornia bigelovii*, again leaving only expanses of muddy salt flats. This association is seldom extensive and only occurs as a marginal fringe between the *Spartina spartinae* association and the *Distichlis spicata* association.

The *Spartina spartinae* association resides on high ground of at least 25. cm (10 in.) above highest tide where inundations occur only during storm tides rather than at the weekly or monthly intervals as found in the *Spartina alterniflora* and *Distichlis spicata* districts. *Spartina spartinae* has minimal tolerance to saline conditions, and inundation for extended periods is fatal to it. The ground, however, usually remains sodden because of poor drainage

and frequent rains, which lower the salinity levels considerably and maintain them most of the year. In the upper portions of the *Spartina spartinae* district (over 91 cm, or 3 ft.), only tropical storm and hurricane-associated floods occur. The *Spartina spartinae* association is easily the most extensive vegetation type of the salt marsh. As much as 50 percent of the total marsh and nearly all of the higher portions of the marsh are dominated by this grass.

AERIAL CHARACTERISTICS OF *DISTICHLIS* AND *SPARTINA PATENS*

To remotely sense *Distichlis spicata* and *Spartina patens*, the grasses most commonly associated with *Aedes sollicitans* breeding, it is necessary to identify them at various altitudes.

In the Galveston test site, *Distichlis* forms essentially pure stands of grass which resembles a lawn from a distance. Each grass plant is composed of a stem 7.5 to 45. cm (3 to 18 in.) tall with two ranks of leaves, each 7.5 cm (3 in.) long, slender, and slightly curved. *Distichlis* forms extensive mats of almost pure grass and with only an occasional *Salicornia virginica* mixed among the grass. Typically, the mat is very dense. The lawn-like appearance is very diagnostic and is recognizable at altitudes in excess of 305. m (1,000 ft.). Therefore, identification of *Distichlis* should be possible from any low-flying aircraft or imagery taken over a salt marsh. Diagnostic characteristics of this association include the short, fine-leaved stature, the occurrence on mud flats, the lawn-like uniformity, the vast pure populations, the gray-green summer color and straw-yellow winter color, and the ability to be flooded for weeks each winter without dying out.

The second important association is a rather small one composed solely of *Spartina patens*. The community is common in Louisiana and to the east and north of Galveston County, but is not common in the immediate Galveston mosquito test site.

Spartina patens is best characterized by its medium-green long, narrow foliage which gives a silky hair-like effect when viewed in context with the other marsh land communities. The grass stands 38 to 61 cm (15 to 24 in.) tall, forms clumps, and frequently occurs near *Distichlis spicata*. The two grasses are easily separated because the lawn-like *Distichlis* differs markedly from the soft and hair-like *Spartina patens*. Additionally, color or black-and-white infrared photographs of the marsh separate *Spartina patens* from all other grasses in the marsh.

CONCLUSIONS

Careful analysis of appropriate literature reveals that the occurrence of salt marsh mosquitoes (Aedes solluctions) may be tied to particular vegetation types; i.e., *Distichlis spicata* and *Spartina patens*. Analysis of the Galveston salt marsh community,

reveals five major plant associations ranging from sea level to 91 cm (3 ft.) in elevation. The associations are *Spartina alterniflora*, *Distichlis spicata*, *Spartina patens*, salt flats, and *Spartina spartinae*. From aircraft overflights at various altitudes, characteristics that identify *Distichlis spicata* and *Spartina patens* were defined. These characteristics may be used in identifying the associated mosquito-breeding areas either visually or by remote sensing.

REFERENCES

1. Matheson, Robert. *Handbook of the Mosquitoes of North America.* New York: Hafner Publishing Co., 1966.

2. Bates, Marston. *The Natural History of Mosquitoes.* New York: Harper and Row, 1965.

3. Bidlingmayer, W. L.; and Schoof, H. F. "The Dispersal of the Salt Marsh Mosquito, *Aedes taeniorhynchus* (Wiedermann) Near Savannah, Georgia." *Mosquito News*, 17 (3), 202-212, 1957.

4. Gordon Gunter, Gulf Coast Research Laboratory at Ocean Springs, Mississippi, verbal communication, 1974.

5. Ferrigno, Fred. "A Two-Year Study of Mosquito Breeding in the Natural and Untouched Salt Marsh of Egg Island." Proc. 45th Meeting of the New Jersey Mosquito Extermination Assoc., 1958, pp. 132-139.

6. MacCreary, Donald. "Observations on Mosquito Larval Habitats and Associations in Delaware." Proc. 42nd Meeting of the N.J. Mosquito Extermination Assoc., pp. 73-80, 1955.

7. Bidlingmayer, W. L.; and Klock, J. W. "Notes on the Influence of Salt Marsh Topography on Tidal Action." *Mosquito News*, 15 (4), 231-235, 1955.

8. Chapman, H. C.; and Ferrigno, F. "A Three-Year Study of Mosquito Breeding in Natural and Impounded Salt Marsh Areas in New Jersey." Proc. 43rd Meeting of N. J. Extermination Assoc., pp. 48-65, 1956.

9. Elmore, C. M.; and Fay, R. W. "*Aedes sollicitans* and *A. Taeniorhynchus* Larval Emergence from Sod Samples." *Mosquito News*, 18 (3), 230-233, 1958.

10. Darsie, Richard F., Jr.; and Springer, P. F. Three Year Investigation of Mosquito Breeding in Natural and Impounded Tidal Marshes in Delaware. Univ. of Del. Argic. Exp. Sta., 1957.

11. Penfound, W. T.; and Hathaway, E. S. "Plant Communities in the Marsh Lands of Southeastern Louisiana." *Mosquito News*, 18 (3), 1938.

12. Penfound, W. T. "Southern Swamps and Marshes." *Botanical Rev.*, 18, 413-446, 1952.

13. Gould, F. W. *Texas Plants: A Checklist and Ecological Summary.* Texas A&M Agric. Exp. Sta., 1969.

14. Correll, D. S.; and Johnson, M. S. *Manual of the Vascular Plants of Texas.* Texas Research Foundation, 1970.

15. Gould, F. W. *Grasses of the Texas Coastal Bend.* Texas A&M Press, 1965.

16. Woodard, D. B.; and Chapman, H. C. "Hatching of Flood Water Mosquitoes in Screened and Unscreened Enclosures Exposed to Natural Flooding of Louisiana Salt Marshes." *Mosquito News*, 30 (4), 545-550, 1970.

17. Dr. W. F. Pippin, Lockheed Electronics Company, Inc., oral communication, 1974.

18. Felton, H. L. "The Breeding of the Salt Marsh Mosquito in Midwestern States." *Jour. Ecol. Entomol.*, 37 (2), 245-247., 1944.

19. McGaughey, W. H. "Role of Salts in Oviposition Site Selection by the Black Salt Marsh Mosquito *Aedes taeniorhynchus* (Wiedermann)." *Mosquito News*, 28 (2), 207-217, 1968.

20. Ostergaard, R.; Murphy, R.; and Auten, D. K. "*Aedes sollicitans* Breeding in Fresh Water." Proc. 48th Meeting N. J. Mosquito Extermination Assoc., pp. 121-122, 1961.

21. Funlow, B. W.; and Hays, K. L. "Some Influences of Aquatic Vegetation on the Species and Number of *Culicidae (Diptera)* in Small Pools of Water." *Mosquito News*, 32 (4), 595-599, 1972.

22. Jouvet, P.; Yi, P. G.; Ree, H. I.; and Lee, K. W. Application of Phytoecological Cartography to Detect the Mosquito Breeding Places on an Island in the Yellow Sea, Korea. WHO/VBC/74.485, 1974.

23. Rioux, J.; Croset, H.; Corre, J.; Simoneau, P.; and Gras, G. "Phytoecological Basis of Mosquito Control Cartography of Larval Biotypes." *Mosquito news*, 28 (4), 572-581, 1968.

TABLE I. – SUMMARY OF THE PLANT COMMUNITIES AND ASSOCIATED GROUND ELEVATION IN THE GALVESTON MOSQUITO TEST SITE

Ground elevation		Plant communities in the Galveston mosquito test site	Environmental notes
Cm.	In.		
121.9	48	Trees	
60.9 - 182.8	24 - 72	Shrubs, grasses	Hurricane and tropical storm tide zone
60.9 - 121.9	24 - 48	Mixed grasses	
25.4 - 91.4	10 - 36	*Spartina spartinae*	Occasional flooding
25.4 - 60.9	10 - 24	*Salicornia/Monanthochloe* + void	Occasional flooding
20.3 - 39.4	8 - 12	*Spartina patens*	Monthly high tide and seasonal wind
15.2 - 25.4	6 - 10	*Distichlis spicata*	Monthly high tide and seasonal wind
7.6 - 20.3	3 - 8	*Batis* + void	Tide zone
7.6 - 15.2	3 - 6	*Spartina alterniflora* + void	Tide zone
0	0		Mean high tide on a calm day

TABLE II. – REFERENCE KEY TO THE SALT MARSH ASSOCIATION

Vegetation	Association
Barren areas boarded by small shrubby mounds	Salt flats
Vast lawn-like expanses of green to gray-green grass	*Distichlis spicata*
Circles or expanses of reedy coarse grass	*Spartina alterniflora*
Circles or expanses of low uniform shrubs with light-green leaves and often conspicuous stems (not a grass)	*Batis maritima*, component of the *spartina alterniflora*
Clumps or tufts of stiff, coarse wire-like grass	*Spartina spartinae*
Clumps or tufts of soft, silky green hair-like grass	*Spartina patens*

PREDICTION OF HEALTH LEVELS BY REMOTE SENSING

E-4

By Marjorie Rush, Ph.D., University of Texas School of Public Health, and
Sally Vernon, M.A., University of Texas School of Public Health

N76-17490

ABSTRACT

Measures of the environment derived from remote sensing were compared to census population/housing measures in their ability to discriminate among health status areas in two urban communities. Three hypotheses were developed to explore the relationships between environmental and health data. Univariate and multiple step-wise linear regression analyses were performed on data from two sample areas in Houston and Galveston, Texas. Environmental data gathered by remote sensing were found to equal or surpass census data in predicting rates of health outcomes. Remote sensing offers the advantages of data collection for any chosen area or time interval, flexibilities not allowed by the decennial census.

INTRODUCTION

Population health status is a response to multi-factoral circumstances, one of which is the urban environmental set. Several authors believe that states of health and disease are linked to environmental factors and express attempts to adapt to changes in the environment (e.g., DuBos, 1965 and Stallones, 1972). Certain of these factors are revealed by remote sensing in the form of aerial photography and are readily discernible by an image analyst. Poverty and density are two environmental conditions, which can be delineated on aerial photographs (Mumbower and Donoghue, 1967; Bowden, 1968; Wellar, 1968; Manji, 1968; Mullens, 1969; and Horton and Marble, 1970). These conditions have been found to be related to health by previous investigators (e.g., Loring, 1964; Lieberman and Duhl, 1964; Schmitt, 1966; Faris and Dunham, 1967; Galle, et al, 1972; and National Health Survey, 1972). The purpose of this study was to determine the applicability of a new health data source--remote sensing--in assessing health levels in two communities. Such data may expedite placement of health intervention, monitoring, or treatment units. This remote sensing capability was demonstrated in studies of both Houston and Galveston, Texas (Rush and Vernon, 1973 and Rush, Goldstein, and Hsi, 1974).

HYPOTHESES

Based on a review of environmental health literature, an empirical generalization was formulated: land use and residential quality of an area are associated with the health status of the population residing in that area. Three hypotheses were developed:

1. Environmental variables revealed by remote sensing can predict mortality and morbidity rates.
2. Population and housing variables reported by the Census can predict mortality and morbidity rates.
3. There is no difference in the health predictive strengths between environmental variables and census variables.

METHODOLOGY

Subareas within Houston and Galveston were described by three sets of data. The independent variables consisted of two sets of ecological data--environmental data interpreted from photography and population/housing data from the 1970 Census. Dependent variables were selected measures of population health responses. Health data were compared with the spatial distributions of visual, physical, environmental characteristics identified from photography. The association of census population/housing data with the health variables was also measured to serve as a standard for comparison of the predictive strength of remotely perceived environmental data.

Data for both cities were collected by census block groups. Thirty-seven block groups in Houston were chosen for a representational cross-section of socio-economic residential levels and industry. In Galveston, a 50% areal sample of 70 block groups was chosen representing discrete urban subareas with homogeneous environmental characteristics.

Environmental data were determined from low level color photography. For Houston the scales were 1:6,000 and 1:12,000 while for Galveston it was 1:24,000. The viewing scale for photo interpretation in both studies was 1:6,000. Regular color photographs were taken of Houston while color infra-red film was used in Galveston. Interpretation of land uses and quality was performed by lot, then recorded by block on a map overlay by the photo interpreter. Quantification by square feet of each land use was carried out by a point counting technique for Houston and by a scaled grid for Galveston. Although the measurement techniques differed, testing indicated no significant differences in results between techniques.

In the Houston study, eleven land use categories were identified and residential land use was further broken down into density and quality classes making a total of 22 categories (Table I). Three residential density classes were used: high (under 60' frontage), medium (60' - 90') and low (+90'). Apartments formed a separate category. Four quality designations were made by the interpreter based on subjective evaluation of house and lot size, curbs and gutters, sidewalks, garages, streets, foliage and mixed land uses.

In the Galveston study, nine land use categories were identified. Two categories of multi-family housing replaced the apartment category in Houston. The quality variables used for a subjective evaluation in both studies were also assessed separately by percentage of block coverage for Galveston.

Health outcomes common to both studies were mortality, tuberculosis, shigella and salmonella, infectious hepatitis and meningitis (Table II). For Houston, first offense juvenile delinquency referrals and mental health referrals were also used. The Galveston study utilized venereal disease (syphilis and gonorrhea), hypertension, and cardiac arrest/myocardial infarction as additional health outcomes. Data were gathered for a time period of from two to eight years except for mortality in both studies, juvenile delinquency in Houston, and venereal disease (VD) and tuberculosis (TB) in Galveston which were collected for one year. These behavioral and morbidity data are subject to errors of underreporting, unsystematic reporting, and problems of definition generally recognized.

Morbidity and behavioral data were converted to crude rates per 1,000 population. Houston mortality data were standardized by sex and three age groups through the indirect method, and the difference between this rate and the crude rate for each block group was used for analysis. For Galveston three standardized age-adjusted rates were utilized. Only three age groups were available on the block group level, and this constituted a limitation in the analysis. Incidence rates were calculated for all morbidity data except TB for which a prevalence rate was used for Galveston.

Univariate and multiple step-wise linear regression analyses were performed on the data. The percentages of explained variation (R^2) were compared after ten steps in the regression equations.

RESULTS AND ANALYSIS

HYPOTHESIS 1: Environmental variables revealed by remote sensing can predict mortality and morbidity rates.

This hypothesis was supported by data from both cities. All 16 multiple correlation coefficients between the environmental variables and health outcomes reached statistical significance of at least .05 (Table III). Fifty percent or more of the variation in the health outcomes was explained in seven cases after ten steps of the regression equations.

In the Houston study, the environmental variables explained 50% or more of the variation for shigella/salmonella (68%), infectious hepatitis/meningitis (50%), juvenile delinquency (57%), and mental health referrals (66%). In Galveston the health outcomes for which the environmental data set explained the most variation were TB (82%), meningitis (73%), and VD (74%).

The data collected by remote sensing were subdivided into density and quality variables for descriptive purposes. These correspond to the environmental conditions of

density and poverty, previously demonstrated by others to be health related.

In both studies, census measures of density were internal measures of overcrowding while the physical environmental variables measured external density. In the Houston study, the environmental variables representing density ("schools," "residential medium density," and "apartments") explained the most variability for mental health referrals (35%) and juvenile delinquency (21%) while for mortality and TB they explained somewhat less (10% and 12% respectively). The environmental density variables in the Galveston study were not strong predictors for any of the health outcomes.

The environmental variables representing quality seemed to be stronger predictors of the infectious disease categories in Houston. For infectious hepatitis/meningitis, nonresidential land uses designating quality were the most important. "Unimproved land" entered first and accounted for 16% of the variation. This land use, particularly in low income neighborhoods, is frequently associated with the presence of litter and other unsanitary environmental conditions. "Streets" was the next variable to enter the equation explaining an additional 17% of the variability. Streets, like unimproved land may be a collection point for litter and rubbish which foster the spread of these communicable diseases. In lower income neighborhoods where front and back yards are practically nonexistent, streets and unimproved land may serve as play areas for children. Residential quality was the most important explanatory variable for shigella/salmonella. Both "fair" and"excellent" quality were inversely related to this disease rate explaining 35% of the variability. The three highest quality categories acted similarly in their relationship to all health outcomes. As expected, only poor quality housing showed a positive relationship to health.

The conclusions reached in measuring quality with environmental variables in the Galveston project were generally similar to those reached in the Houston project and were consistent with the literature, i.e., that poverty neighborhoods measured by poor housing and poor environmental conditions seem to be the setting for higher disease rates than neighborhoods of middle and upper income levels. For TB, the quality variable "parking lots" accounted for 57% of the variance while the "number of square feet per dwelling unit," which could be considered either a density or quality variable, accounted for an additional 13% of the variance. "Litter," "industry," and "multi-family residence" explained 63% of the variations in the VD data.

In addition to the infectious disease categories, mortality also showed a relationship to environmental quality variables in the regression models for Galveston. The first three variables accounting for 36% of the variation in mortality under age 18 were "industry," "parking lots" and "narrow lot frontages." For mortality, ages 18-61, the variables accounting for 35% of the variation were "house size," "industry" and "vacant land."

In Houston, remote sensing environmental variables representing both quality and density were important while in Galveston those representing quality showed stronger predictive ability. The pattern of association between the quality variables and the health outcomes in both Houston and Galveston was generally similar, i.e., quality variables were good predictors of infectious disease rates, with the addition of mortality in Galveston.

HYPOTHESIS 2: Population and housing variables reported by the Census can predict mortality and morbidity rates.

This hypothesis was also given support with twelve of the sixteen multiple correlation coefficients reaching statistical significance of .05. In seven cases 50% or more of the variation in health outcomes was explained.

The health variables which were explained by the census variables differed somewhat between the two studies. In Houston after ten steps 50% or more of the variations in the TB (65%), shigella/salmonella (72%), mortality (50%), and juvenile delinquency (55%), data were acounted for by census variables while in Galveston census data predicted at least 50% of the TB (54%), cardiac arrest/myocardial infarction (50%), and VD (71%) variations.

Census variables also consisted of both environmental quality and density measures.

Density as measured by census variables was not an important explaining variable for any of the health outcomes in the Houston study. Census derived quality measures appeared to be slightly stronger predictors of health levels than density measures for both cities. Ten of the sixteen first place variables entering each equation could be considered quality indicators. However, of the first two variables entering the equations half were labeled quality and half density. The four strongest census predictors were "% Black," "% 1 person households," "average value of owner occupied dwellings" and "% rental units." These indicators were the strongest predictors of mortality, TB, and mental health referrals for Houston while they were good predictors of VD, TB, hypertension and meningitis in Galveston.

The mix in the equations of quality and density variables from both remotely perceived and census data reflects the strong relationship between environmental quality and density. They are interacting variables which support one another in their relationship to health outcomes.

HYPOTHESIS 3: There is no difference in the health predictive strengths between environmental variables and census variables.

In eleven of the sixteen cases variation explained by environmental data was greater than that by census data. In only one of the five cases where census variables explained more variation was the difference in predictive strength greater than 10%.

It can be seen from Table II that the environmental variables in the Houston study had a higher level of association with three of the dependent health variables. In two cases--infectious hepatitis/meningitis and mental health referrals--the differences were substantially higher, 26% and 22% respectively. In only one of three cases where the census variables had greater predictive strength was the difference great--20% in the case of TB. For the other two--mortality and shigella/salmonella--the differences were slight, 8% and 4% respectively. Overall, however, in the Houston study the results showed about equal predictive strength for both environmental and census data sets.

In the Galveston study the environmental variables outperformed the census variables (Table III). The results showed that for eight of the ten dependent health variables, environmental variables accounted for a greater level of association and predictive strength than census variables. This suggests that environmental variables may be considered surrogates for the usual health correlates.

In only two cases, hypertension and cardiac arrest/myocardial infarction, did the predictive strength of the census model exceed that of the environmental model and in both of these cases the differences were slight, amounting to 4% and 5% respectively. This result is significant in that both health variables are chronic diseases and had not been expected to show strong association with the physical environment. It appears that even for chronic diseases the physical setting may act as a surrogate for social characteristics when examining the ecological distribution of these diseases.

The predictive strength of environmental variables in explaining mortality variation for all age groups in Galveston reached 42%, 49% and 26% respectively. These mortality models all reached significance of 5%, while only one age category (18-61) reached 5% significance in the census model. Since the mortality data is the most valid data set in the group of dependent variables, these data support the utilization of physical environmental variables in ecological studies of mortality, a frequently used measure of health status.

CONCLUSION

Environmental data derived from aerial photographs were found to equal or surpass census data in predicting health levels of urban subareas in the two communities studied. However, the environmental surrogates of health outcomes need to be validated in other communities. Remote sensing may offer an alternative data source to health planners. It may be both a faster and more current source than present ground survey methods in delimiting public health problem areas.

ACKNOWLEDGEMENTS

This investigation was partially funded by Contract NAS 9-12823, National Aeronautics and Space Administration, Johnson Space Center, Houston, Texas. Dr. Bartholomew P Hsi, Associate Professor of Biometry, University of Texas School of Public Health served as Statistical Consultant. Ms. Sally Vernon served as Project Director for the Houston study and Ms. Janice Goldstein served as Project Director for the Galveston study. Mr. Calvin B. Olsen performed the image analysis on both cities.

REFERENCES

Bowden, L. W.
1968 Multi-sensor Signatures of Urban Morphology, Function and Evolution. Technical Report No. 2, U.S.D.A. Contract No. 14-08-0001-10674. Departments of Geography, University of California at Los Angeles and Riverside.

DuBos, R.
1965 Man Adapting. New Haven: Yale U. Press.

Faris, R. E. L. and H. W. Dunham
1967 Mental Disorders in Urban Areas. Chicago: University of Chicago Press.

Galle, O. R., W. R. Gove and J. M. McPherson
1972 "Population Density and Pathology: What are the Relations for Man?" Science 176, April 7: 23-30.

Horton, F. E. and D. F. Marble
1970 "Housing Quality in Urban Areas: Data Acquisition and Classification through the Analysis of Remote Sensor Imagery," in Second Annual Earth Resources Aircraft Program Status Review Vol. I, Part 15, Houston, Texas Manned Spacecraft Center: 1-13.

Lieberman, E. J. and L. J. Duhl
1964 "Physical and Mental Health in the City," The Annals of the American Academy 352: 13-24.

Loring, W. C.
1964 "Residential Environment: Nexus of Personal Interactions and Healthful Development," Journal of Health and Human Behavior 5, Winter: 166-169.

Manji, A. S.
1968 The Uses of Conventional Aerial Photography in Urban Areas: A Review. Technical letter NASA-131, Washington, D.C.: U.S. Geological Survey.

Mullens, R. H., Jr.
1969 "Analysis of Urban Residential Environments Using Color Infrared Aerial Photography: An Examination of Socio-economic Variables and Physical Characteristics of Selected Areas in the L.A. Basin," Interagency Report NASA-153.

Mumbower, L. E. and J. Donoghue
1967 "Urban Poverty Study," Photogrammetric Engineering 33: 610-618.

National Health Survey
1972 "Health Characteristics of Low-Income Persons." National Health Survey, Series 10, No. 74, Mary Lou Bauer, (ed.) U.S. Dept. of H.E.W., Health Services and Mental Health Administration, Rockville, Md., (July).

Rush, M. N. and S. Vernon
1973 Urban Environmental Health Applications of Remote Sensing, Contract NAS 9-12823, The University of Texas Health Science Center at Houston School of Public Health, December, 1973, (Unpublished).

Rush, M. N., J. Goldstein and B. P. Hsi
1974 Urban Environmental Health and Remote Sensing, Galveston, Texas, Contract NAS 9-12823, The University of Texas Health Science Center at Houston School of Public Health, November, 1974, (Unpublished).

Schmitt, R. C.
1966 "Density, Health, and Social Disorganization," Journal of the American Institute of Planners 32 (Jan.): 38-40.

Stallones, R. A.
1972 "Community Health," Science 175, No. 4024 (25 February).

Wellar, B. S.
1968 Generation of Housing Quality Data from Multi-band Aerial Photographs. Interagency Report NASA-119, Washington, D.C.: U.S. Geological Survey.

TABLE I. - LAND USE CATEGORIES HOUSTON AND GALVESTON

HOUSTON		GALVESTON	
1-12	Residential-Single Family Quality: Excellent, Good, Fair, Poor Density: High, Medium, Low	1	Residential-Single Family
		2	Multi-family 1-3 story
		3	Multi-family +3 stories
13	Apartments		
14	Commercial	4	Commercial
15	Industrial	5	Industrial
16	Unimproved	6	Vacant & Unimproved
17	Parks & Recreation Areas	7	Open Space
18	Cemetaries		
19	Churches	8	Community Facilities
20	Schools & Educational facilities		
21	Hospitals & Health-related facilities		
22	Streets	9	Parking Lots

TABLE II. - HEALTH OUTCOMES HOUSTON AND GALVESTON

HOUSTON	GALVESTON
Mortality-sex and age group adjusted (3)	Mortality - ages 17 and under Mortality - ages 18-61 Mortality - ages 62 and over
Tuberculosis (incidence)	Tuberculosis (prevalence)
Shigella & Salmonella	Shigella & Salmonella
Infectious hepatitis & Meningitis	Infectious hepatitis Meningitis
Juvenile delinquency	
Mental health referrals	
	Venereal disease
	Hypertension
	Cardiac arrest/myocardial infarction

TABLE III. - EXPLAINED VARIATION (CUMULATIVE MULTIPLE CORRELATION COEFFICIENT SQUARED) OF FIRST 10 VARIABLES IN STEP-WISE REGRESSION HOUSTON AND GALVESTON

Health Outcome	Houston		Galveston	
	Environmental Variables	Census Variables	Environmental Variables	Census Variables
	R^2	R^2	R^2	R^2
Tuberculosis	.45	.65	.82	.54
Shigella/Salmonella	.68	.72	.42	.25
Hepatitis			.28	.16*
Meningitis			.73	.29
Inf. Hep/Men	.50	.24*		
Mortality	.42	.50		
Under Age 18			.42	.20*
Ages 18-61			.49	.35
Over 61			.26	.12
Cardiac Arrest/MI			.45	.50
Venereal Disease			.74	.71
Hypertension			.45	.49
Juvenile Delinquency	.57	.55		
Mental Health Referrals	.66	.44		

*All variables were significant at the .05 level except those marked with this symbol

APPLICATION OF EREP, LANDSAT AND AIRCRAFT IMAGE DATA TO ENVIRONMENTAL PROBLEMS RELATED TO COAL MINING

E-6

Roger V. Amato*, Orville R. Russell, and Kenneth R. Martin
Earth Satellite Corporation, Washington, D.C. 20006 and
Dr. Charles E. Wier, Indiana Geological Survey,
Bloomington, Indiana 47401

N76-17491

ABSTRACT

The synoptic and repetitive views of aerial remote sensing records offer valuable environmental and dynamic change data in areas of both surface and underground coal mining. Depending upon the accuracy of requirements, these data are available through both low and high level aircraft surveys as well as LANDSAT and EREP (SKYLAB) imagery. Remote sensors can provide timely and accurate information on surface mining status and reclamation progress, coal mine refuse piles and slurry ponds, acid water and siltation problems, and various aspects of environmental impact. With two concurrently-orbiting earth resources satellites (LANDSAT 1 and 2) providing repetitive coverage every nine days, mining-environmental data can be supplied to state and federal agencies in a timely manner. This is particularly important because of the accelerated development of coal resources to meet unprecedented energy demands.

Remote sensing techniques were used to study coal mining sites within the Eastern Interior Coal Basin (Indiana, Illinois, and western Kentucky), the Appalachian Coal Basin (Ohio, West Virginia, and Pennsylvania) and the anthracite coal basins of northeastern Pennsylvania. Remote sensor data evaluated during these studies were acquired by LANDSAT, SKYLAB and both high and low altitude aircraft. Airborne sensors included multispectral scanners, multiband cameras and standard mapping cameras loaded with panchromatic, color and color infrared films.

The research that has been conducted in these areas is a useful prerequisite to the development of an operational monitoring system that can be periodically employed to supply state and federal regulatory agencies with supportive data. Further research, however, must be undertaken to systematically examine those mining processes and features that can be monitored cost effectively using remote sensors and for determining what combination of sensors and ground sampling processes provide the optimum combination for an operational system. The preliminary studies described in this paper supply information useful for directing the scope of this necessary follow-on research.

INTRODUCTION

Surface mining for coal is expanding rapidly to meet increasing energy needs and at the same time both the public and government are placing increasing emphasis on ensuring that coal and other minerals can be extracted from the earth with a minimum of environmental damage. This increasing concern over the adverse environmental effects of surface mining is resulting in the need for the acquisition of a large quantity of new data related to mining and mined land reclamation and for a rapid and cost effective means of such data acquisition.

* Now with the U.S. Geological Survey, Washington, D.C.

Remote sensors can provide timely and accurate information on surface mining status and reclamation progress, coal mine refuse piles and slurry ponds, acid water and siltation problems, and various aspects of environmental impact. Depending upon the accuracy of requirements of various user agencies, these data are available through both low and high level aircraft surveys as well as LANDSAT and EREP (SKYLAB) imagery. With two concurrently-orbiting earth resources satellites (LANDSAT 1 and 2) providing repetitive coverage every nine days, the potential exists for providing mining-environmental data to state and federal agencies in a timely manner.

This paper summarizes the results of several investigations in which remote sensing records were used to supply data on various environmental problems related to both surface and underground coal mining. These investigations were made on coal mining sites in the Eastern Interior Coal Basin (Indiana, Illinois, and western Kentucky), the Appalachian Coal Basin (Ohio, West Virginia and Pennsylvania) and the anthracite coal basins of northeastern Pennsylvania. Remote sensor data evaluated during these studies were acquired by LANDSAT, SKYLAB and both high and low altitude aircraft. Airborne sensors included multispectral scanners, multiband cameras and standard mapping cameras loaded with panchromatic, color and color infrared films.

LANDSAT IMAGERY

LANDSAT imagery has proven useful for detecting changes resulting from active mining and from land reclamation developments. The spatial resolution of the system is, however, a significant problem, particularly for small areas of only a few hectares. Since one pixel element is almost 0.5 hectare in size, the averaging of energy in a pixel that extends across a boundary of mined and non-mined land can produce erroneous area measurements of substantial dimensions. The larger the mined area, the smaller the percentage of error that will be encountered.

Based on this fact, the potential for the application of LANDSAT imagery to mined land monitoring are greater for states with area1/ mining than for states with contour mining.

The discrimination of mined land features is somewhat limited on LANDSAT imagery. For instance, it is difficult to identify land disturbed by actual mining and that disturbed by other associated activities, particularly the systematic removal of vegetation in advance of actual stripping operations. Also, as mined land is revegetated, it blends into the non-disturbed land and is difficult to identify.2/ This is illustrated in Figure 1. The reflective properties of freshly mined spoil (A) is similar to the exposed strata (B) where the soil cover has been removed. Partially revegetated

---

1/ The term "area" mining" is normally used for surface mining in low relief terrain where the overburden can be totally removed and all the coal extracted, thus large areas are uniformly disturbed. "Contour mining is restricted to areas of high relief and the coal bed is uncovered in a narrow band around the mountain. As many of the coal beds where this technique is used lies nearly horizontal, the stripping essentially follows the contour of the mountain, thus the name.

2/ This, of course, is one of the objectives of mined land reclamation and the difficulty mentioned extends to analysis of aerial photography and even to ground observations if the land is well reclaimed.

mine spoil (C) will have a reflective character intermediate between bare rock and undisturbed land (D). Reclaimed land which has been reseeded to grasses (E) has reflective properties much like the natural terrain (D).

LANDSAT imagery can be employed for delineation of freshly stripped non-mined land, and for making one or two intermediate classifications of stages of revegetation.

SKYLAB (EREP) IMAGERY

The larger scale of SKYLAB photography in comparison to LANDSAT imagery offers a greater potential for acquiring surface mined land information usable by state and federal agencies.

To determine the degree of utility of SKYLAB imagery and to make comparisons between SKYLAB, LANDSAT and aircraft imagery for such studies, two test sites in the Eastern Interior Coal Basin were selected. These sites were the Sullivan area south of Terre Haute in western Indiana and the Millport area in Muhlenburg and Hopkins counties of northwestern Kentucky.

Sullivan, Indiana Test Site

The area between Sullivan and Terre Haute, Indiana was selected as a test site for surface mining because of the presence of (a) several large active surface mines, (b) large areas of older reclaimed and unreclaimed mined land and (c) two large underground coal mines. Black and white enlargements of the S-190B color and color infrared imagery were made to determine the maximum scale to which the imagery could be enlarged without excessive image deterioration and to determine the optimum scale(s) for visual analysis. To test analysis quality at different scales, photographic enlargements were made to 1:500,000, 1:250,000, 1:100,000, 1:50,000 and to 1:24,000, the latter a 40X enlargement. The 1:250,000 and 1:100,000 scale enlargements proved most useful for this investigation.

The 1:250,000 scale enlargement was compared with a recently published (June, 1972) strip mine area map of Indiana. This analysis revealed significant advances of strip mining in the Dugger, Jasonville and Sullivan areas, and the opening of a new mine near Hymera. Land which has been strip mined and reclaimed recently (within the past 5 years) was evident; however, on the SO-242 film, older mined lands overgrown with trees were difficult to differentiate from the nearby unmined farm and forest lands. However, in areas of medium to high contrast, changes in mined areas as small as 1 hectare could be identified visually on the imagery.

Analysis of the 1:100,000 scale, black and white S-190B enlargements indicated that nearly all past and current, if less than 75% vegetal covered, could be accurately delineated and that one or two classes of reclamation assessment could be detected. Cultural detail at this scale was adequate for positioning the mine delineations accurately on existing base maps.

A 1:24,000 black and white enlargement was made of the large, active Minnehaha Mine to determine if S-190B data was suitable for updating existing large scale mined land maps or for use as 7-1/2' quadrangle-sized, photobase, mined-land maps. This enlargement illustrated in Figure 2 is about the maximum enlargement permissible for SKYLAB S-190B imagery without excessive image deterioration. Although the mined areas could be readily delineated (especially where high contrast exists between the freshly mined soil and rocks and the much darker surrounding vegetation), the resolution of the enlargement at this scale was not adequate to produce the detail and accuracy deemed necessary for some state and federal agency needs. At this scale, high contrast mined

areas could be delineated with a tolerance of $\pm$ 1mm ($\pm$ 17 meters), whereas some of the lower contrast, previously reclaimed areas could only be delineated with a line accuracy of $\pm$ 2.5mm or about 60 meters.

Millport, Kentucky Test Site

The Millport test site was selected because of previous investigations in the areas and the availability of considerable ground truth data. This site, with its thin soil cover and bedrock exposures also contrasts with the Sullivan test site which is overlain with a varied thickness glacial drift cover up to several meters thick. A mined land inventory map was prepared at 1:24,000 scale using quadrangle centered 1:80,000 scale panchromatic photography. LANDSAT and SKYLAB imagery were evaluated for possible use in updating this map. A 1:24,000 scale enlargement was made from S-190B color infrared imagery of this 7-1/2' quadrangle area, and enlargements to 1:80,000 scale were made of both SKYLAB (Figure 3) and LANDSAT (Figure 4) imagery to compare directly with the high altitude aerial photographs. The SKYLAB imagery was acquired on September 15, 1973, whereas the highest quality LANDSAT frame for this same area, and the one used in this study, was acquired on September 30, 1972. Mined land maps prepared from the aircraft, SKYLAB and LANDSAT images formed the basis for determining the detail of delineation possible with each type of imagery.

The enlarged SKYLAB imagery allowed discrimination of eight categories of mining activity and reclamation (Figure 5). These include areas which have been mined but are essentially bare soil and rock, areas mined with 50 to 100% revegetation, unmined areas, refuse areas and slurry ponds, water bodies, highwalls, haulage roads and other types of activity associated with the mining of the coal. The investigators could not differentiate contour mining from area mining in this site on SKYLAB imagery although some contour mining could be delineated with stereo viewing of the high altitude aircraft photography. The SKYLAB color infrared imagery proved moderately good for identification of areas which had been revegetated although distinguishing between different degrees of vegetal cover was difficult. This imagery clearly differentiates water bodies from coal mine refuse and slurry ponds. Highwalls were also identified where high contrast existed between the mined area and the surrounding vegetation. Consecutive S-190B image frames were studied stereoscopically, but the relatively low relief in the area minimized the advantage of the third dimension. It did provide binocular image reinforcement and an apparent improvement in image quality.

The six categories of mined land reclamation and features identified on the LANDSAT Band 7 enlargement of the same area (Figure 6) included some highwalls, mined lands with 50% or more vegetal cover, mined lands with less than 50% vegetal cover, mined lands with essentially bare soil or rock, unmined lands, and water bodies or coal mine refuse areas. The quality of the LANDSAT imagery severely deteriorated at the 1:80,000 scale enlargement, but it still showed high contrast between the mined and unmined areas and proved superior to the SKYLAB imagery for rapidly mapping lands disturbed by surface mining.

Disadvantages of LANDSAT compared to SKYLAB include the lack of resolution of distinguishing cultural features to aid in transferring the data accurately to geographic base maps, the inability to distinguish between mine refuse areas, i.e. refuse piles and slurry ponds and naturally occurring or other mining - related water impoundments. Other features associated with surface mining such as haulage roads, railroads, mine preparation plants and areas being cleared or readied for surface mining were also difficult or impossible to identify.

It appears from this comparison that once an accurate data base has been established from aerial photography, high quality LANDSAT imagery[3/] enlarged to scales as much as 1:100,000, could be used on a regional basis if accuracy requirements are not stringent. Repetitive imagery with resolution approximating the S-190B camera would provide significantly superior data for monitoring mining and reclamation activities.

A portion of the SKYLAB S-190B color infrared imagery was also enlarged to a scale of 1:24,000. The greater clarity and contrast of vegetational boundaries on the color infrared imagery (EK 3443) rendered an enlargement considerably superior for analysis to the S-190B color film (SO-242) enlargement of the Sullivan test site. However, the resolution and contrast of these enlargements were not adequate to provide the accuracy of mined land delineations deemed necessary for most state requirements. It did, however, within the accuracies possible, provide substantial data for updating the existing 1:24,000 scale mined lands map produced from the high altitude aerial photography acquired 2-1/2 years before.

AERIAL PHOTOGRAPHY

Aerial photography of various scales and film types have been used to investigate a wide range of environmental problems produced by surface and underground mining.

Small scale (1:120,000) color infrared photography acquired by NASA provided an excellent media for evaluating a variety of mined land problems to an accuracy that will satisfy most potential users. Resolution of this film and scale are such that detection of moderate contrast targets is possible if the size exceeds about 5-10 meters. Target sizes for identification and mapping, however, are more of the order of 10-15 meters. Such imagery is adequate for mapping both mining and reclamation progress, and presenting the data on 1:24,000 scale base maps. The degree of regrading and replanting is easily discernable and accurate assessments of vegetal ground cover rapidly made. Mapping units of two hectares or more are practical although units of a fraction of a hectare are possible. Such imagery does lack the resolution for resolving individual tree sets used in reclamation or for accurately mapping the detail of acid mine drainage.

The color rendition of the 1:120,000 scale color infrared photography provides an added dimension for interpretation, and the subjective judgment of the analysts are that, with this film and image scale, interpretations are more readily made and are as accurate as that attained on 1:80,000 panchromatic photography.

A practical application of 1:120,000 color infrared photography for mined land studies was made recently in Indiana as part of a LANDSAT-1 experiment. The photography was used to map the refuse piles and slurry ponds for the entire coal field area of Indiana. Information developed was provided to the Indiana State Legislature to assist them in designing legislation for the reclamation of such features. The disposal sites of the coal waste from preparation plants were identified, located by township, range and quarter section and plotted on 1:250,000 scale base maps.

The image of each coal refuse site was optically enlarged and classified. However, area measurements on sites less than .8 hectare (2 acres) was not attempted. Sites

---

3/ Experience in the midwest area of the United States indicates that atmospheric vapor or haze seriously degrades much of the LANDSAT imagery and that an image of superior clarity may be acquired only once or twice a year.

were segregated into three primary height classes based on stereoscopic examination and acreage values were computed with a polar planimeter. Quality control of data obtained from the small scale color infrared aerial photography included spot checking with 1:20,000 scale color and color infrared aerial photography, where available, ground and light aircraft observations. Reclamation costs for each site were estimated by integrating data derived by remote sensing with statistics acquired from industry and government sources.

Efforts were made to identify those areas where acid drainage, vegetation damage, or stream sedimentation were present. The proximity of refuse areas to drainage systems was also noted.

Small scale (1:80,000) panchromatic photography of western Kentucky was used to test the utility of such imagery for surface mined-land classification. This photography permitted mapping of twenty-two separate categories of mined land disturbances, reclamation and mining features. These categories included areas of active strip mining, three categories of vegetal cover where no reclamation grading had occurred, three classes of vegetal cover where only partial grading had occurred, three vegetal cover classes where complete reclamation grading had occurred, three vegetal cover classes for graded and ungraded contour mining, plus the identification of water bodies, coal preparation areas, coal refuse areas, delineation of high walls, and the identification of areas disturbed by mining activities although not actually mined. Figure 7 is a portion of the photobase map prepared at a scale of 1:24,000.

Large-scale imagery is useful for detailed reclamation assesssment, including monitoring of slope angle, spoil type classification and seedling and grass growth and survival; other environmentally degrading factors which can be monitored are the identification and location of acid spoil and acid mine drainage sources, siltation sources and deposition sites, classification of materials in mine refuse dumps, and burning refuse piles.

A further demonstration of the use of remote sensor data for identifying the environmental effects of mining was recently completed. With aircraft support of NASA-Lewis Research Center, a mine subsidence mapping program was conducted for the Pennsylvania Department of Environmental Resources and the Appalachian Regional Commission. In this study, the utility of various types of large-scale aircraft imagery were evaluated for the detection of surface subsidence features. The remote sensing data used for the investigation included LANDSAT-1 imagery, side looking airborne radar (SLAR) imagery, multispectral scanner imagery for 11 spectral bands (including thermal infrared), color, color infrared and panchromatic aerial photography. LANDSAT imagery of all seasons was available whereas most of the other remote sensor data was acquired in winter or spring. NASA-Lewis Research Center acquired the SLAR, MSS imagery and the color, color infrared and panchromatic photography in the spring of 1974 specifically for this investigation. Additional aerial photography was obtained from NASA, U.S. Geological Survey, and the Pennsylvania Department of Environmental Resources. Complete photographic coverage of the Northern Anthracite Field was obtained for the years 1974, 1973, and 1969, and selected areas were studied using photographic coverage from as far back as 1949.

Significant results of the investigation include the verification of aerial remote sensing as an accurate method of mapping surface subsidence features in the anthracite coal fields of Pennsylvania. More than 1,000 such features were identified in the Northern Anthracite Coal Field which were previously unrecorded and unknown. The subsidence features were classified as pothole (Figure 8), regional, or linear based on interpretation keys and developed in the study on field verification. Early spring or late winter proved to be the optimum times for acquiring aerial photography for subsidence detection in the northeastern United States. Large-scale (between 1:10,000 and

1:20,000) color, color infrared and panchromatic photography were most useful for subsidence analysis. Table 1 summarizes the results of the subsidence investigations.

CONCLUSIONS

We believe this research is a useful prerequisite for developing an operational monitoring system for state and federal regulatory agencies. The synoptic and repetitive views of satellite and aerial remote sensing imaging systems offer the potential of deriving valuable enviornmental and dynamic change data in areas of both surface and underground coal mining. Depending upon the accuracy requirements, these data are available through both satellite and low and high level aircraft surveys.

Integration of remote sensing monitoring systems into the state mined land regulatory programs depends upon many factors that differ substantially from place to place due to state requirements and the environment.

At present, it appears that for most state requirements for around-the-year, surface mined land monitoring, LANDSAT, or imagery of comparable resolutions, is of limited value. Not only are most of the necessary judgments of mined land status difficult or impossible to make on the best quality of such imagery, but, in many parts of the United States, the acquisition of cloud free imagery is uncertain. However, for periodic, e.g., yearly updating of regional surface mine maps, LANDSAT may provide sufficient accuracies for some users. With appropriate baseline data, LANDSAT can provide information rapidly and economically for updating progress of new mining and reclamation of mined land.

Satellite imagery of S-190A and S-190B quality offers greater potential for use in routine monitoring programs, and if available on a continued basis, undoubtedly would find application by state agencies concerned with mined land reclamation. A real question still exists, however, as to what extent analysis of satellite imagery would replace or supplement current monitoring procedures and what the real cost savings would be.

These questions are largely academic unless the data are put in the user's hands in a timely manner. For example, the assessment of reclamation quality for release of bond monies requires timely information. The identification and apprehension of mining companies conducting illegal mining requires the acquisition and prompt analysis of the imagery to be an effective surveillance method.

Aerial photography, particularly color and color infrared types, can provide data for the evaluation of virtually all surface mining activities ranging from pre-planning of mining activities, through actual mining and reclamation to an acceptable state. The scale of photography and film type used depends upon the specific requirements of the investigation. 1:120,000 scale imagery is sufficient for reliable regional assessment of mining activities, whereas, large scale photography better provides engineering data and detail of acid mine problems. Table 2 is a summary assessment of the utility of the various remote sensor data for mined land investigations.

No one has made a systematic evaluation of aerial photography for mined land studies, either from a technical or economic point of view. However, the U.S. Bureau of Mines has just initiated a project to do this. The results of this study and of current LANDSAT studies may provide the impetus needed to encourage state regulatory agencies concerned with mining to incorporate remote sensing data into their programs.

REFERENCES

Amato, R.V., et al., Application of Remote Sensor Data to Environmental Problems in Coal Mining Regions. Geological Society of America. Abstracts with Programs Vol. 7, No. 1.

Deely, D.J., et al., 1973, Applications of Aerial and Orbital Remote Sensing to the Study of Mined Lands. Research and Applied Technology Symposium on Mined Land Reclamation Proceedings, Pittsburgh, Pennsylvania.

Earth Satellite Croporation, 1971, Mined Land Map Series, Millport, Kentucky 7-1/2 minute Quadrangle Photobase Map and Explanation. Washington, D.C. 20006.

Powell, R.L., 1972, Map of Southwestern Indiana Showing Areas Strip Mined for Coal. Indiana Geological Survey, Miscellaneous Map, No. 15.

Wier, C.E., et al., 1974, Application of ERTS Imagery to Indiana Mining Problems. Ninth International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan.

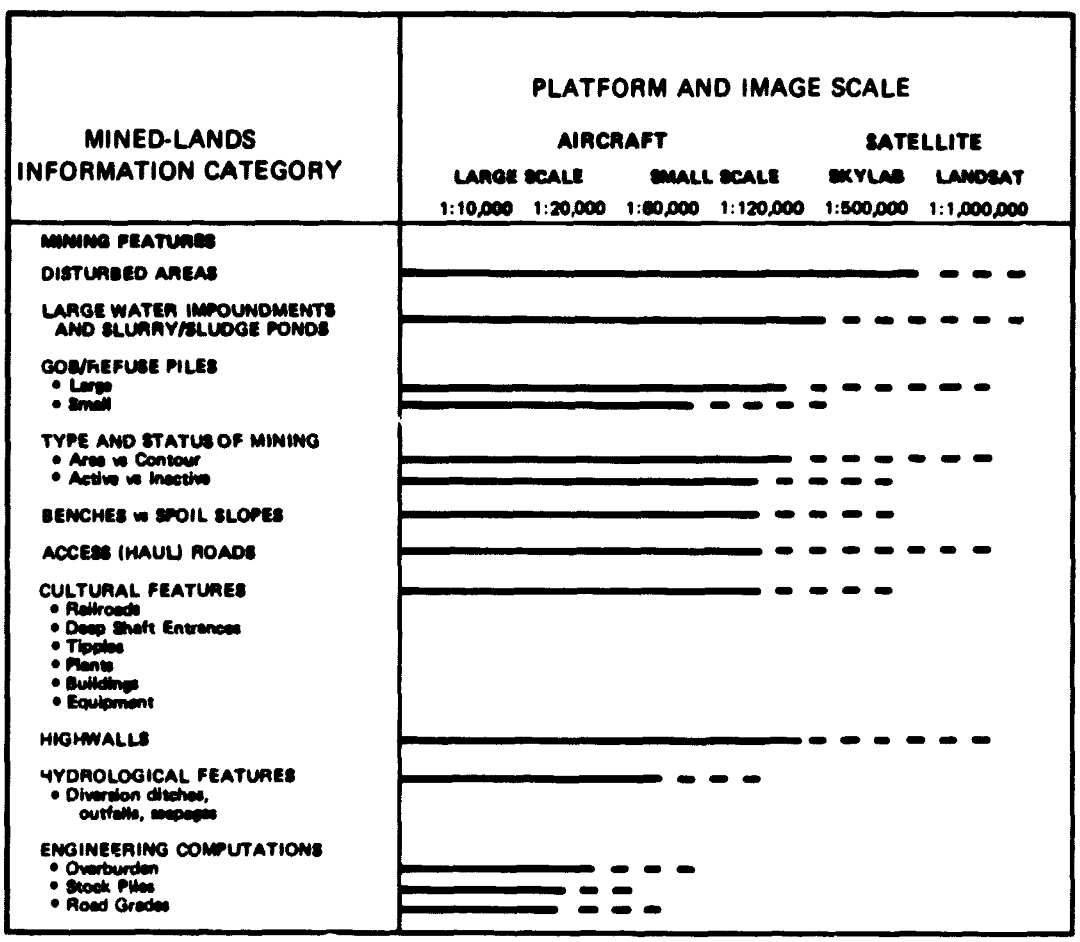
Wier C.E., et al., 1974, Application of ERTS-1 Imagery to Fracture Related Mine Safety Hazards in the Coal Mining Industry. Final Report for NASA Contract NAS5-21795. ERTS Program Office, Goddard Space Flight Center, Greenbelt, Maryland.

Wier, C.E., et al., (In preparation) Application of EREP Imagery to Fracture-Related Mine Safety Hazards in Coal Mining and Mining-Environmental Problems in Indiana. Final Report, NASA Contract NAS9-13358. SKYLAB, Principal Investigations Management Office, Lyndon B. Johnson Space Center, Houston, Texas.

TABLE 1. UTILITY (AS TO SCALE) OF REMOTE SENSORS USED FOR ANALYSIS OF MINE SUBSIDENCE

SENSOR DATA USED	USABLE SCALES	UTILITY	OPTIMUM SEASON
LANDSAT-1 Imagery	1:1,000,000-1:250,000	Detection of regional Lineament and Fault patterns	Various; Band 5, 7 Spring, Autumn
SLAR IMAGERY	1:500,000-1:100,000	Fracture detection	Various; Spring, Winter, Autumn
Small Scale Photography	1:130,000-1:90,000	Detection of Fracture traces and regional subsidence	Early Spring
Color infrared (IR) photography	1:30,000-1:130,000	Detection of regional subsidence, fracture traces and pothole subsidence	Spring
Color Photography	1:30,000-1:130,000	Detection of regional subsidence and fracture traces	Spring
Panchromatic, color IR, color aerial photography	1:16,000-1:30,000	Detection of regional subsidence, fracture traces, and linear subsidence (extension)	Late Winter, Spring
Panchromatic, color, color IR aerial photography	1:10,000-1:16,000	Detection of pothole subsidence, linear subsidence, fracture traces, regional subsidence, environmental impact analysis	Late Winter; Early Spring
Thermal imagery	1:20,000-1:10,000	Regional subsidence detection	Spring

TABLE 2. UTILITY OF DIFFERENT SCALES OF IMAGERY FOR EFFECTIVE IDENTIFICATION OF SELECTED MINED-LAND FEATURES



LEGEND

GENERALLY USEFUL; REQUIRES SKILLED IMAGE ANALYSTS TO ACQUIRE MOST USEFUL RESULTS.

USEFUL WITH DIFFICULTY.

TABLE 2 (Cont'd - 2). UTILITY OF DIFFERENT SCALES OF IMAGERY FOR EFFECTIVE IDENTIFICATION OF SELECTED MINED-LAND FEATURES

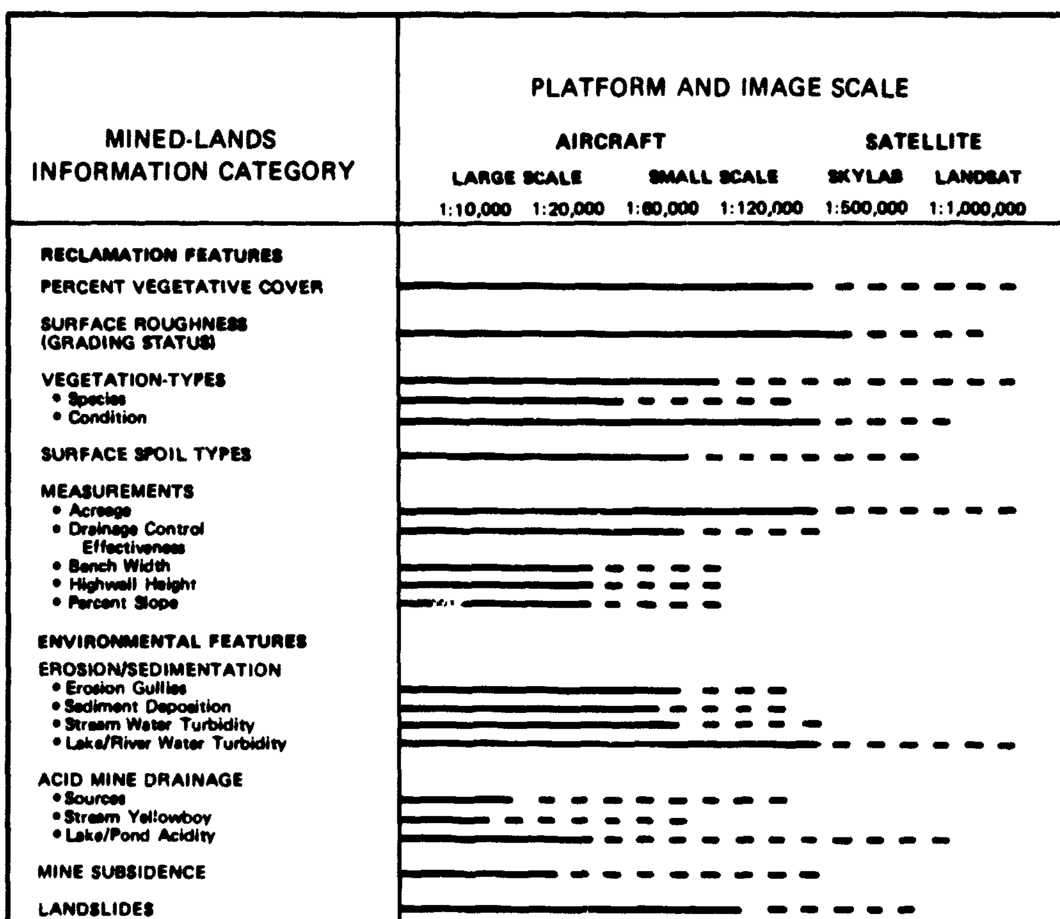


FIGURE 1. This aerial oblique view of surface coal mining activity illustrates a wide variety of land disturbances associated with this industry. Area (A) is freshly disturbed overburden material. Area (B) has had the soil layer removed in preparation of mining. Area (C) is older, ungraded spoil piles which were seeded to grasses and trees with partial reclamation success. Area (E) has been graded to a rounded topography and seeded to grasses. Such lands blend well with the natural terrain (D) and are difficult to differentiate on satellite imagery.

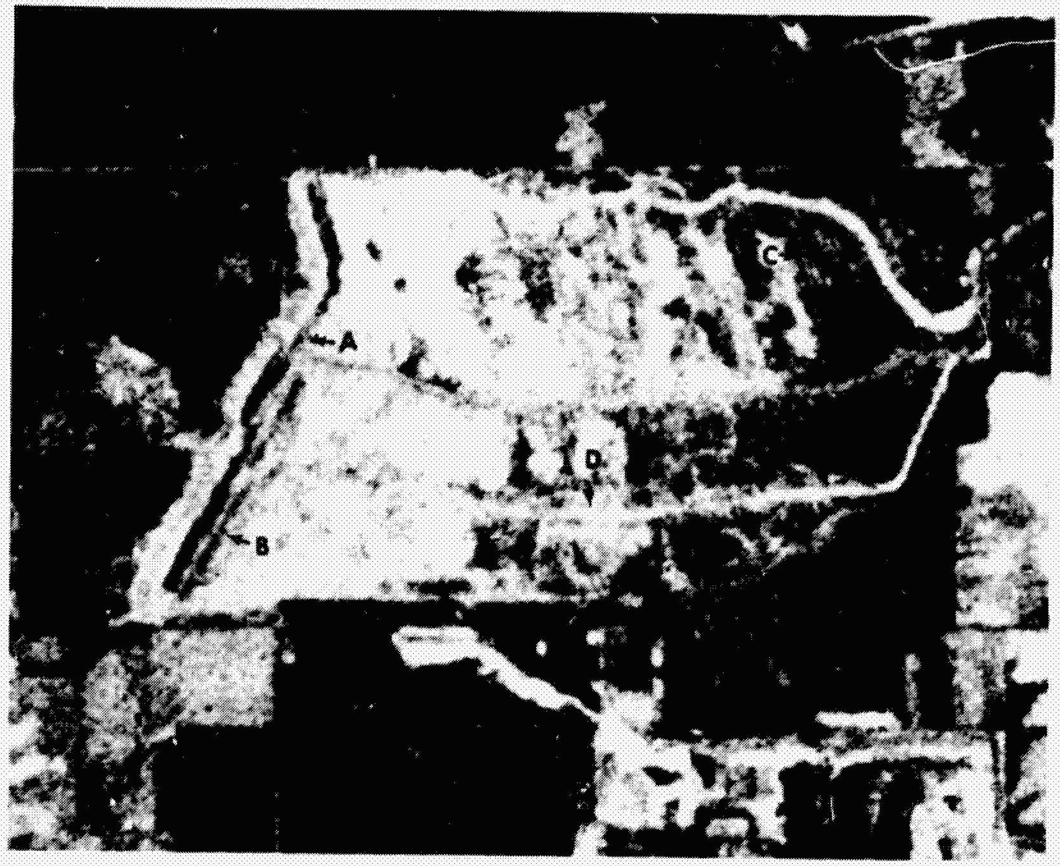


FIGURE 2. Black and white enlargement to 1:24,000 scale of SKYLAB S-190B color image of the large Minnehaha surface mine in the Sullivan, Indiana test site. A large dragline used for removing the overburden can be distinguished on the original image at (A) as can be the highwall and the current mining furrow. Two ridges of ungraded mine spoil are evident at (B). Land reclaimed under old mining laws which did not require the ridges to be leveled is identifiable at (C). The old and current haul roads are obvious at (D). The older, now unused, road is imaged with less contrast.

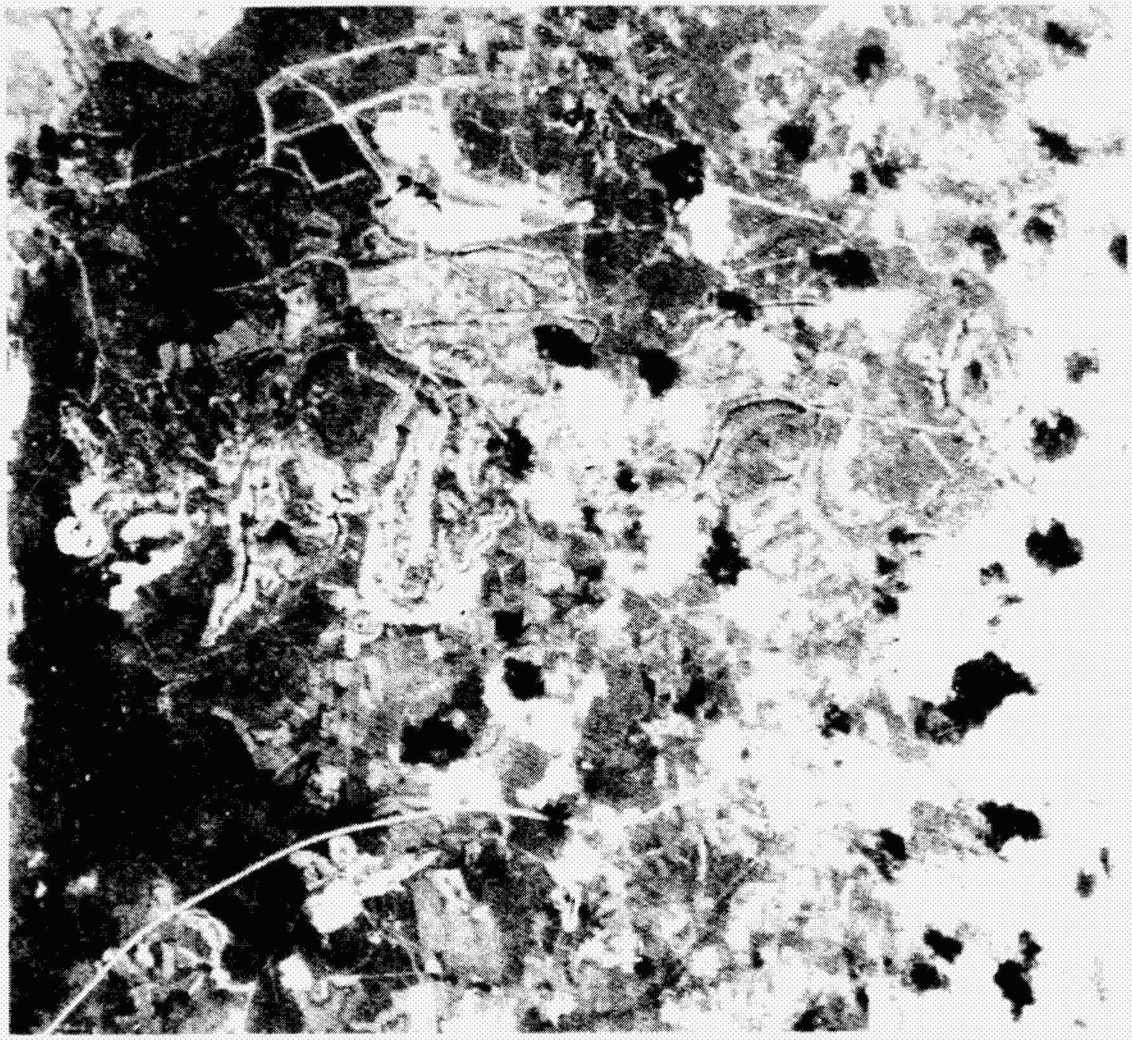


FIGURE 3. This 1:80,000 scale image is a black and white rendition of a SKYLAB S-190B color infrared photograph acquired in September, 1973 over the Millport, Kentucky test site. Although a few scattered clouds appear on the imagery, the quality and resolution were sufficient to permit mapping of eight categories of mined land disturbance.

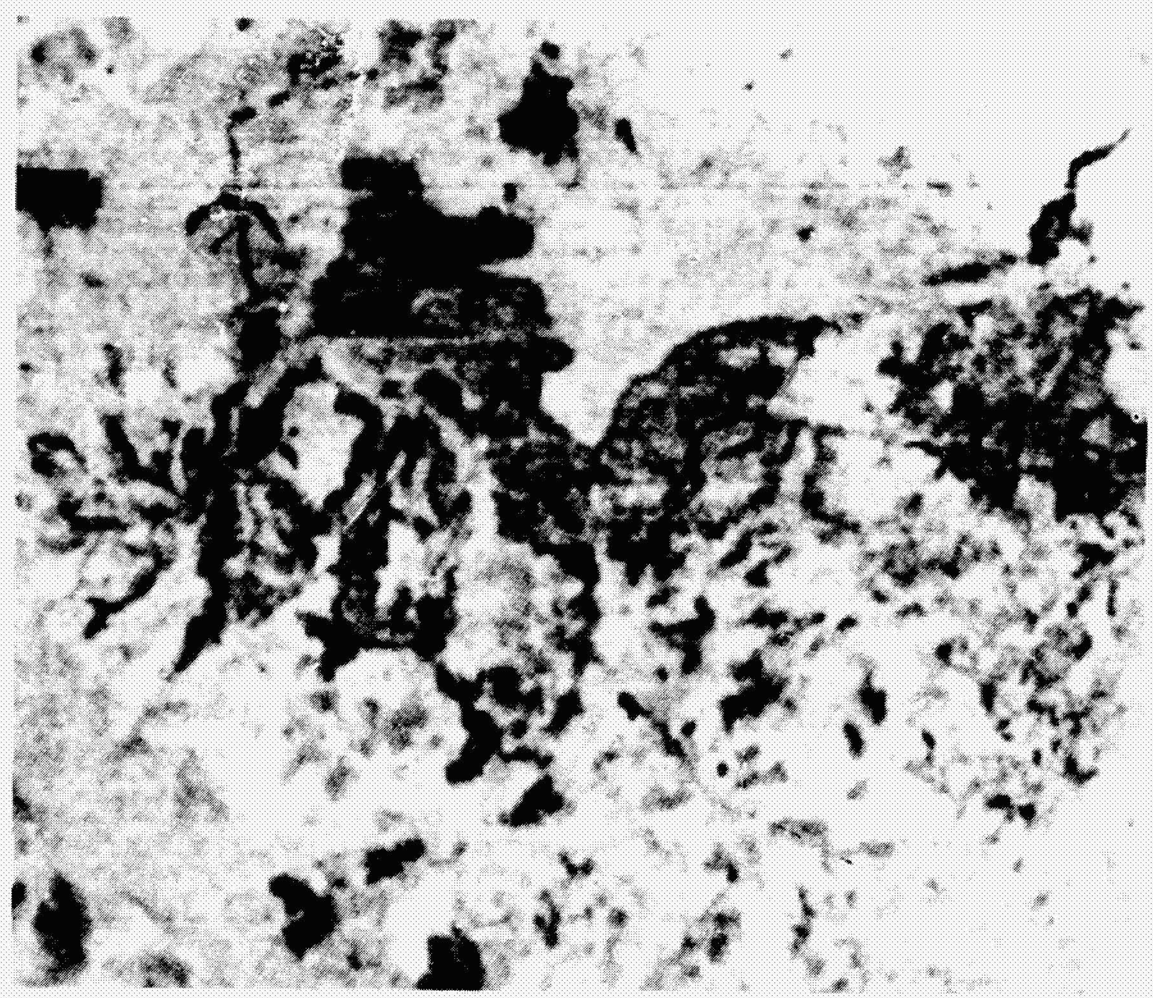


FIGURE 4. LANDSAT-1 image of the Millport, Kentucky area enlarged to approximately 1:80,000 scale. This Band 7 image (No. 1069-15594) was acquired on September 30, 1972 and provides some of the highest contrasts between mined and unmined lands seen on LANDSAT imagery of this test site.

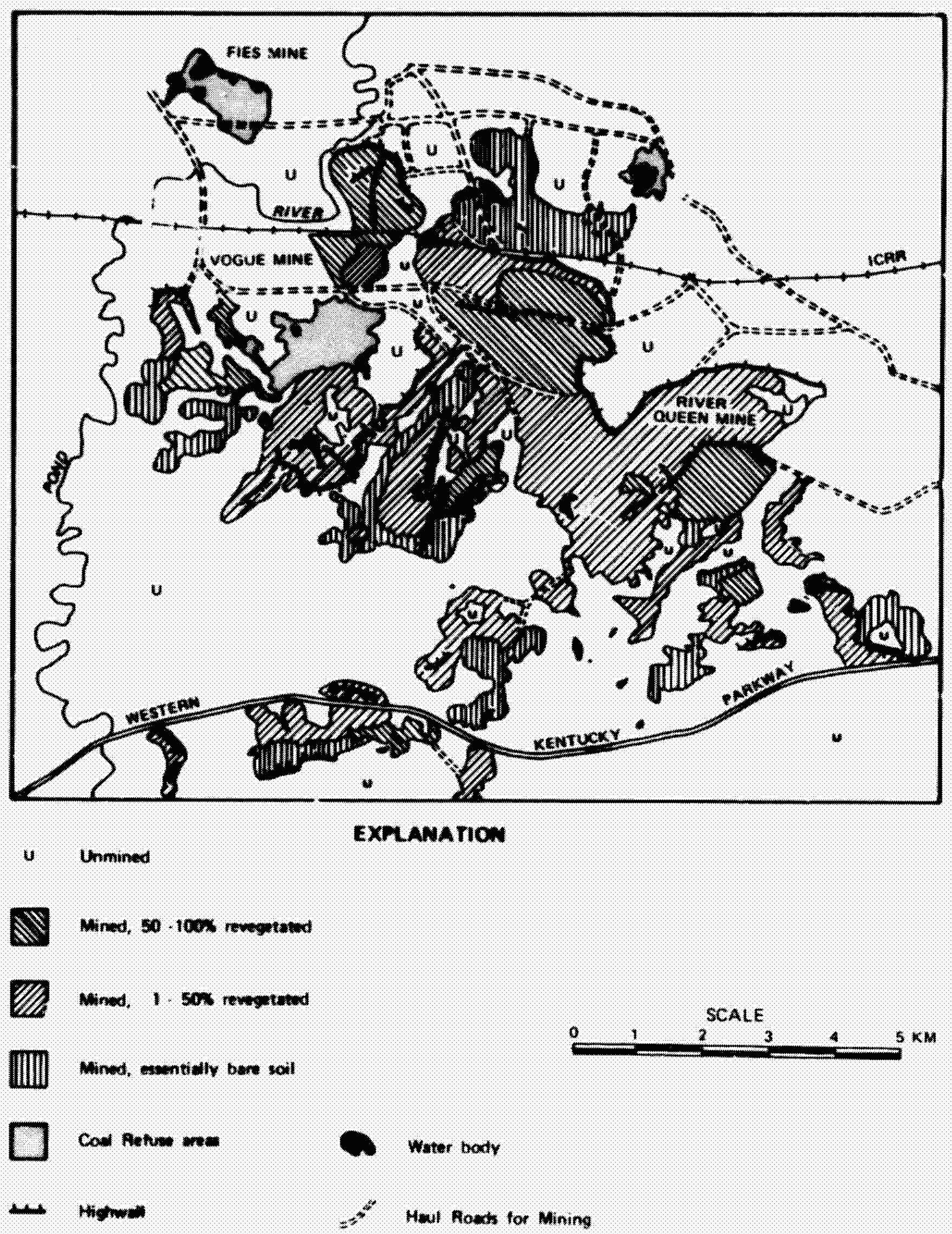


FIGURE 5. Map of surface mining disturbance features delineated from SKYLAB S-190B (September 15, 1973) imagery of the Millport, Kentucky area shown in Figure 3.

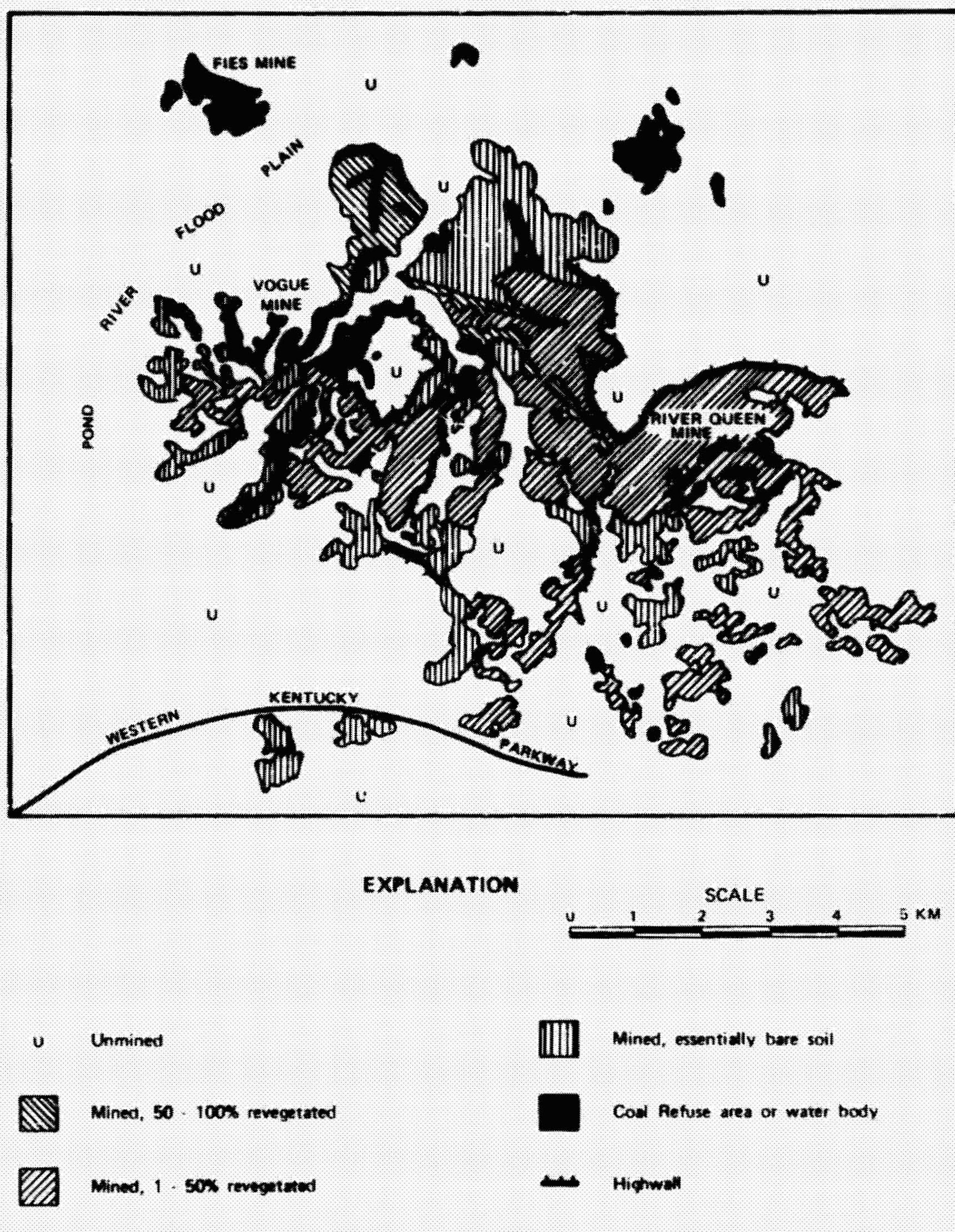


FIGURE 6. Map of surface mining disturbance features delineated from LANDSAT-1, Band 7 imagery shown in Figure 4. Differences between this map and that made from the SKYLAB imagery shown in Figure 3 are mainly attributed to the problem on LANDSAT imagery of accurately distinguishing between reclaimed land and vegetated non-mined land.

LEGEND

110	STRIP MINING,	ACTIVE		
111	STRIP MINED,	NO GRADING	0-25%	VEGETAL COVER
112	STRIP MINED,	NO GRADING	25-50%	VEGETAL COVER
113	STRIP MINED,	NO GRADING	50-75%	VEGETAL COVER
121	STRIP MINED,	GRADED, RIDGE TOPS LEVELED	0-25%	VEGETAL COVER
122	STRIP MINED,	GRADED, RIDGE TOPS LEVELED	25-50%	VEGETAL COVER
123	STRIP MINED,	GRADED, RIDGE TOPS LEVELED	50-75%	VEGETAL COVER
131	STRIP MINED,	GRADED, ROLLING TERRAIN	0-25%	VEGETAL COVER
132	STRIP MINED,	GRADED, ROLLING TERRAIN	25-50%	VEGETAL COVER
133	STRIP MINED,	GRADED, ROLLING TERRAIN	50-75%	VEGETAL COVER
210	CONTOUR MINING,	ACTIVE		
211	CONTOUR MINED,	NO GRADING	0-25%	VEGETAL COVER
212	CONTOUR MINED,	NO GRADING	25-50%	VEGETAL COVER
213	CONTOUR MINED,	NO GRADING	50-75%	VEGETAL COVER
231	CONTOUR MINED,	GRADED, ROLLING TERRAIN	0-25%	VEGETAL COVER
232	CONTOUR MINED,	GRADED, ROLLING TERRAIN	25-50%	VEGETAL COVER

L – LAKE OR POND
P – COAL PREPARATION PLANT
S – SLURRY REFUSE AREA
——— HIGH WALL
G – GOB REFUSE AREA
D – DISTURBED AREA ASSOCIATED WITH PREPARATION PLANT

FIGURE 7. This image is a portion of an annotated photobase map prepared from 1:80,000 scale panchromatic photography. The map was prepared at a scale of 1:24,000 and is presented here at a scale of about 1:50,000. Although good results were obtained with this type and scale of imagery, 1:120,000 scale color infrared photography permits better discrimination of reclamation status.

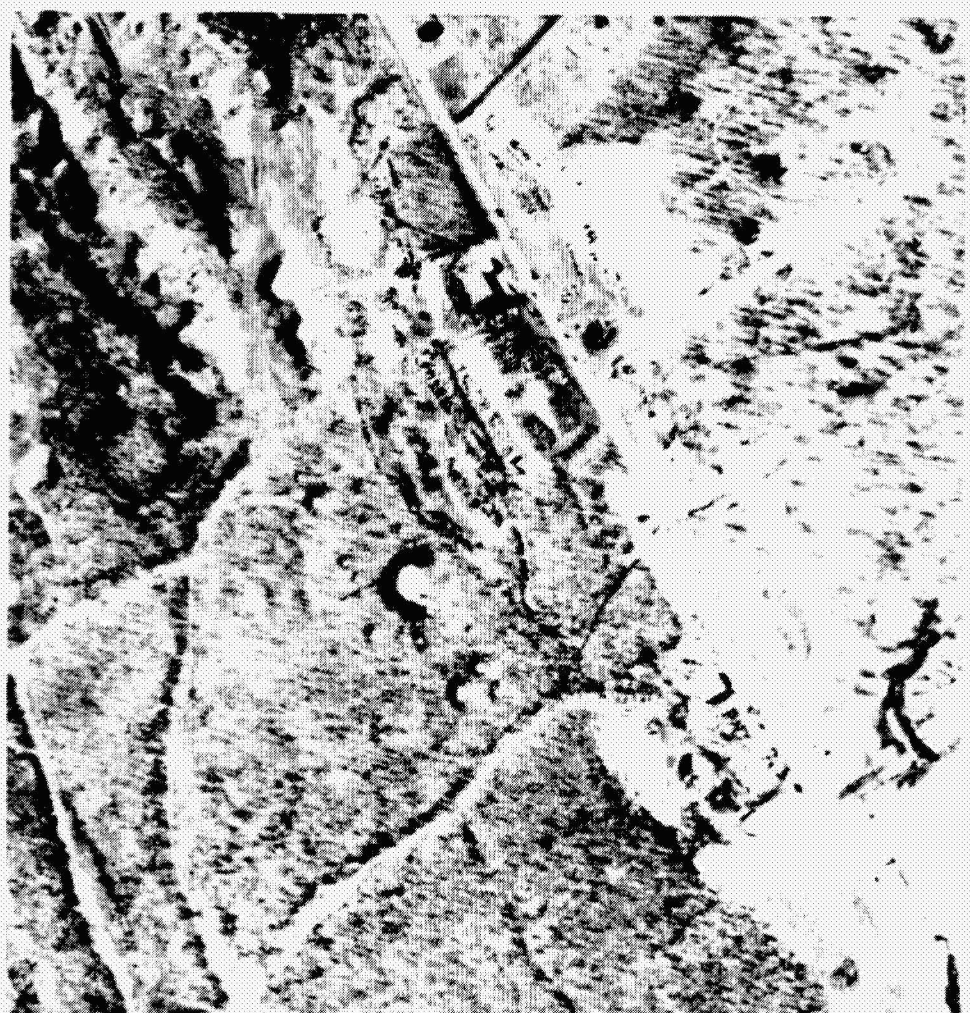


FIGURE 8. This 1:6,250 scale enlargement of a 1:16,000 scale panchromatic aerial photograph is an excellent illustration of pothole subsidence features as they occur in the anthracite coal fields of eastern Pennsylvania. Such subsidence features are usually the result of mining the coal seam too close to the surface or to the base of unconsolidated valley fill.

LANDSAT INVENTORY OF SURFACE-MINED AREAS USING EXTENDIBLE DIGITAL TECHNIQUES

E-7

By Arthur T. Anderson, Earth Resources Branch NASA/GSFC, Greenbelt, Maryland;
Dorothy T. Schultz, General Electric Company, Beltsville, Maryland; and
Ned Buchman, General Electric Company, Beltsville, Maryland

N76-17492

ABSTRACT

Multispectral analysis of LANDSAT imagery provides a rapid and accurate means of identification, classification, and measurement of strip-mined surfaces in Western Maryland. Four band analysis allows distinction of a variety of strip-mine associated classes, but has limited extendibility. A method for surface area measurement of strip mines, which is both geographically and temporally extendible, has been developed using band-ratioed LANDSAT reflectance data. The accuracy of area measurement by this method, averaged over three LANDSAT scenes taken between September 1972 and July 1974, is greater than 93%. Total affected acreage of large (50 hectare/124 acre) mines can be measured to within 1.0%.

INTRODUCTION

Extraction of near-surface coal by surface or "strip" mining techniques is an economically feasible response to the Nation's growing demand for energy. In order to reduce dependence on foreign imports, coal mining activity has increased greatly in the last year, and will continue to do so as new reserves are opened. The Nation's need for energy, however, must be balanced with the environmental consequences of coal exploitation. Surface mining unaccompanied by reclamation renders the land useless for other productive uses. Property near or adjoining mine sites is degraded in value (Ref. 1), and severe erosion, landslides, flooding, air and water pollution may also occur.

Of the estimated 2.2 million acres of land stripped for coal in the United States, only a third has been reclaimed (Ref. 2). Frequent monitoring by regulatory agencies is required to insure reclamation success. National reclamation standards do not yet exist and requirements vary widely among the 23 states which presently regulate strip mining. Thus, information on the location, size, and condition of mines is often lacking or inadequate. In a cooperative NASA/State of Maryland effort, imagery relayed from the NASA Earth resources satellite (LANDSAT-1)[1] was applied to the monitoring information needs of the Maryland State Bureau of Mines. The objectives of this cooperative study were (1) determine the accuracy of satellite data for measuring strip mines of the size common in Western Maryland, and (2) develop an operationally feasible procedure for large area inventorying and monitoring of surface mining.

BACKGROUND

The State of Maryland became officially involved in the regulation, monitoring and reclamation of strip mines in 1967 when the State's coal strip mining law was enacted. This law, amended in 1969 and 1971, established a Land Reclamation Committee which administrates the provisions of the act. Under this act, strip mine operators are required to obtain licenses and permits, submit mining and reclamation plans, procure performance bonds, and periodically report on the amount of land area disturbed. All of the disturbed surface, including storage areas for topsoil and spoils, haul roads, and areas disturbed by the movement of equipment, must be reclaimed according to State-approved plans. Mines closed before the law's enactment will be reclaimed by the State.

[1]The LANDSAT program is managed by the NASA/Goddard Space Flight Center, Greenbelt, Md.

To assist in the tasks of planning, monitoring, enforcement, and reclamation, the Maryland State Bureau of Mines needs information on the location, size, and condition of coal surface mining areas. Three mine inspectors presently report monthly on active mining operations within a 1541 square kilometer area (595 square miles). The new regulations and increased coal production will require additional inspectors and more efficient means of data collection.

STUDY AREA

The region studied in this investigation includes most of Garrett County and the adjacent area of Allegany County in Western Maryland. The State's only coal deposits are located in these counties. This region, part of the Allegheny Plateau of the Appalachian Range, consists of gently folded mountains, the result of differential erosion of sedimentary materials which were originally deposited in horizontal layers and were compressed to form a series of parallel mountains and synclinal basins. The co~l-bearing strata are of Pennsylvanian age and lie within 200 feet of the surface in five major basins (Figure 1). The easternmost basin, Georges Creek, contains 233 square kilometers (90 square miles) of intensive strip mine activity. Most of the strip mines in this area follow topographic contours and are 75 to 400 meters wide (250 to 1300 feet). High walls range from 20 to 45 meters (60 to 150 feet). The majority of mines are less than 90 hectares (220 acres) in size. It was within the Georges Creek basin that multispectral training of LANDSAT data was conducted.

METHODS

Area Measurements

Accurate area measurements from aerial photographs were required for this study in order to quantitatively inventory the area affected by surface mining and verify the accuracy of the satellite inventory. Prior to 1975 the State recorded only the area of coal surface annually exposed. For this study, therefore, total affected area was determined by planimetry of NASA/Wallops low altitude aerial photography taken in October 1973 (Figure 2). The area measurements obtained from these photographs were used to verify the accuracy of the LANDSAT classifications for eight surface mines in the test site.

Obtaining accurate area measurements from low altitude aircraft imagery is a difficult, time consuming task due to a combination of factors: off-nadir viewing, the varying elevation of the mines in this area, and the distortion due to the mountainous terrain. The following procedure was followed in calculating the area of each test mine from aircraft photography:

- The mine areas were planimetered four times with precision among these being greater than 96%. (Readings with a large deviation were rejected.) The average of these readings was used in the calculation.
- A table of photo scale versus aircraft altitude was calculated using the formula:

$$\text{Photo scale} = \frac{\text{Focal length}}{\text{Altitude}}$$

- The table of photo scale was verified and corrected using ground distance measurements on the aerial photographs and topographic maps.
- The camera height was determined by subtracting the mean topographic elevation of the mines from the corrected aircraft altimeter readings. Large mines were segmented into sections of nearly equal elevation.

- Using the appropriate photo scale factor the planimetry values were converted to acres.
- The mine acreage values were corrected for the viewing aspect angle.

The surface area measurements obtained in this manner are shown in Table II which is in the Results Section of this paper. The test mines shown in Figure 2 range in size from 12.7ha (31.4 acres) to 98.7ha (243.8 acres). Surface area values from aircraft photos are 25 to 30 percent larger than the published State figures which at that time related only to the coal surface exposed; the aircraft values are for the total affected area including spoil piles and haul roads. For accurate reclamation projections, the State now requires data on this total disturbed area.

High altitude aerial photographs of the Georges Creek basin are available from NASA/Ames for 1972 and 1974. One of the test mines, Franklin Hill-A was planimetered on these photographs because the entire mine was not included on the 1973 low altitude photos. In general, however, the areas of interest were too small and too near the format edge to permit accurate planimeter measurement.

The high altitude photography did show that most of the test mines changed very little in size during the two-year period between the photos. The only test mines whose areas were significantly different from year to year are those located near Mill Run. Mill Run-B had not been opened in 1972, but was completely stripped by October 1973. In 1974 it was backfilled. The lower section of Mill Run-A was bare in 1972 and almost completely revegetated in 1973 (see Figure 2). The other test mines remained approximately the same size from 1972 through 1974.

Multispectral Analysis

An interactive, multispectral image analysis system[2] was used to perform the digital data processing of LANDSAT computer compatible tapes (CCTs). The system's image analysis console houses a color image display, controls, and a special purpose high speed processing logic. A mini-computer together with peripherals serves as a system process controller and computational device. The user interacts directly with the computer through a graphics entry/display terminal. The graphics terminal also serves to display the quantitative processing results in both numerical and graphic form.

<u>Four-band classification</u>.- A portion of LANDSAT-1 scene 1405-15242 (1 Sept. 73) containing the Georges Creek basin was digitally enlarged to fill the system's 512 X 512 picture element color display (Figure 3). The area displayed is approximately 51.8 square kilometers (20 square miles). Supervised training and classification were then performed on the four LANDSAT spectral bands. Training sites were selected with an electronic cursor which is sized and positioned using a joy-stick. The image analysis system's special purpose hardware identifies the spectral reflectance range within the training site in the four LANDSAT bands simultaneously. The minimum and maximum reflectance values in each channel (band) of the training area are then used to define the limits of a 4-dimensional spectral parallelepiped. The picture elements of the entire displayed image are examined pixel-by-pixel. Those pixels lying spectrally within the parallelepiped bounds defined by the training site are identified or "alarmed" on the TV monitor. This entire process requires less than 5 seconds. The system user then has the option of modifying the spectral signature to increase or decrease the alarm through thresholding the parallelepiped boundaries. This procedure is known as single parallelepiped training and classification.

[2] General Electric IMAGE 100 System

In this study single-parallelepiped training was applied to areas within the Georges Creek basin whose surface cover was known from interpretation of the low altitude aerial photography and from field inspection. In certain cases pixels were classified into more than one category. Aerial photographs were then consulted to determine the proper classification, and the signatures of the overlapping classes were modified to eliminate the conflicts.

Seven classes, five of which describe areas affected by strip mining, were identified. Discussion of these classes and their extension throughout the study region is presented in the Results Section of this paper.

Band-ratio classification.- The great variability among 4-band signatures for various types of strip-mining surfaces discourages the use of this means of classification on an operational monitoring basis. A great deal of ground verification data is required, and training must be carried out on each type of surface. This is not only true in Western Maryland, but the Environmental Protection Agency (Ref. 3) has reported great variation among signatures for strip mines studied in Wyoming and Montana. Preprocessing of the LANDSAT multispectral data before classification provides a means of distinguishing strip mines in a single classification. The objective of preprocessing is to transform the sensor outputs to minimize the effects of environmental, observational and sensor conditions on signature extraction. Other investigators (Ref. 4) have found that band-ratioing techniques minimize systemic errors and decrease temporal and geographical differences. The rationale behind ratioing can be illustrated by a simplified model of spectral signal in the narrow bandwidth (i) of a sensor:

$$S_i' = m_i S_i + a_i$$

where S_i' is the observed reflectance and S_i is the reflectance at the surface. If the multiplicative terms are larger than the additive terms and these are approximately invariant over adjacent spectral bands, then when $i+1 = j$, the ratio

$$\frac{S_i'}{S_j} = \frac{m_i S_i}{m_j S_j} = \frac{S_i}{S_j}$$

is not affected by the multiplicative error factors. Hence, multiplicative system errors are minimized in the ratioed signals. Table I, borrowed from Kriegler (Ref. 5), indicates the factors that produce signal variation. Note that most of the factors related to the useful signal are multiplicative. On the other hand, the effects of atmospheric backscatter and noise are additive, and they tend to mask the useful signal.

TABLE I .- GENERAL FACTORS THAT PRODUCE SIGNAL VARIATIONS

Variable Factor	Causes and Dependencies	Type of Factor	
		Multi	Add.
Illumination	Shadows, time of day, clouds, etc	X	
Transmittance	Altitude, haze, aerosols, scan angle	X	
Reflectance	Scan angle, sun angle, species, maturity, vigor	X	
Atmospheric Backscatter	Altitude, haze, aerosols, sun angles		X
Sensor Gain	Different setups, different days	X	
Noise	System components		X (primarily)

Identical portions of the 1 Sept. 73 (1405-15242) and the 6 Sept. 72 (1045-15245) images were preprocessed on the multispectral image analysis system to yield twelve band-ratios for each date. The procedure used to determine the most accurate strip mine classification using these ratios was as follows:

- In both images polygon-shaped training sites were defined to surround each test strip mine.
- Histogram lists of the polygon areas were obtained for all twelve LANDSAT ratios. These provided pixel counts for each mine in several gray level ranges.
- Pixel counts for each mine were converted to surface area. A LANDSAT pixel equals 0.453 hectares (1.12 acres).
- A least squares regression was then calculated for the aircraft area values (y) and the LANDSAT area values (x) for each gray level range, using data from both 1972 and 1973 imagery. The regression resulting in the smallest standard error of estimate was selected as providing the most consistently accurate surface area measurement from both 1972 and 1973 data.

The smallest standard error of estimate, 2.16 hectares, was obtained using the band-ratio of MSS 5/6 (Figure 4). The resulting equation was:

$$y = 0.295 + 0.970x + \epsilon$$

where y is the "true" or aircraft area in hectares; x is the LANDSAT area in hectares; and ϵ is the residual. This equation was used to "adjust" the LANDSAT area measurements for the two images. The MSS 5/6 strip mine signature selected by this procedure was applied to a third satellite image, 1729-15164 of 22 July 1974. The pixel counts for each test mine were converted to hectares and adjusted by the factors in the regression equation. The resulting surface area values for all three images are given in Table II.

RESULTS

Four-band Classification

Using the multispectral analysis system, 4-channel training and classification on sites of known surface characteristics resulted in the identification of seven classes: three strip mine surface classes, bare soil, partially revegetated, and two classes of undisturbed land including forest and open fields. Figure 5 demonstrates the results of this classification of the test site on 1 September 1973 LANDSAT-1 imagery.

Field analysis and communication with the Bureau of Mines revealed several additional details about these classes.

- Strip Mine Class 1 corresponds to the exposed subsoil and the spoil piles of relatively light color, particularly from the Franklin and Barton coal seams. The mines in this class were either open or backfilled with spoil material at the time of the satellite overpass.
- Strip Mine Class 2 denotes the open or backfilled mines of darker subsoil, specifically those associated with the Pittsburg coal seam. The overburden of this seam contains a large quantity of burned shale (rashings), which has a characteristic red color, and therefore, a distinct reflectance signature. The red shale is often used as road surfacing material by the mine operators, and some roads are included in this class.
- Strip Mine Class 3 corresponds to strip mines that have been backfilled and graded, some of which are being used as landfill areas. Most of these mines exposed the Upper Bakerstown coal seam and its associated spoils.

- The Bare Soil Class identifies strip mine surfaces which have been backfilled with the spoil, graded and covered with topsoil. The soil is brighter than subsoil material in all four LANDSAT spectral bands and therefore this class is distinct from the three described above. Some of the mine surfaces included in this class have been seeded but are not yet revegetated.
- The Revegetated Class relates to surfaces which are similar in cover to the sparsely grassed-over airstrip on Franklin Hill, which is an old strip mine that has been approved as revegetated by the State. The boundaries between open strip mines and forests or fields are sometimes falsely included in the revegetated class. This is due to the fact that the average reflectance of the field of view of these boundary pixels is similar to that of sparse vegetation on closed strip mines.
- Open Field refers to unforested land, chiefly crop and grazing land, which has never been stripped.
- Forest refers to areas covered by dense trees and scrub vegetation.

The signatures derived for these seven classes were applied to the entire study area which contains the adjoining areas of Garrett and Allegany Counties in Maryland, and Grant and Mineral Counties in West Virginia. The resulting regional classification is shown in Figure 6.

Certain surfaces are falsely alarmed (classified) when the multispectral signatures are extended over a larger area. For example, the town of Keyser, Maryland, located to the right of center in Figure 6, is classified as strip mine. Apparently the vegetated/non-vegetated contrast in reflectance of the town is similar to that of the mines. Another false alarm includes the railroad yard west of Keyser. The dark railroad bed material is classified in the second strip mine class. The bare soil classification correctly identified areas other than backfilled spoils. Along the west bank of the North Branch of the Potomac River, the construction site of a new rail cut located adjacent to the river was classified as bare soil.

Band-Ratio Classification

Using band-ratioed data and linear regression analysis it was possible to extend a single signature to three LANDSAT images covering a time span of two years. Of the 12 LANDSAT band-ratios, the ratio of MSS 5/6 proved to provide the most consistently accurate results when compared to aircraft planimetry. Using the linear regression equation the standard error of estimate is less than 5 pixel-sized units. The correlation coefficient (r) of the linear regression is 0.997. The results of the band-ratio classification of the Sept. 72, Sept. 73, and July 74 LANDSAT data are presented in Table II and Figure 7.

The average difference from the aircraft photography is $\pm$ 6.9% for all three years. The largest errors occur in the July 1974 image; six of the eight mines are underestimated by an average of 12%. Comparison of the 1974 classification with the 1973 and 1972 classifications and with available air photos suggests that most of this change is due to natural revegetation around the edges of inactive mines. The two Phoenix Hill mines (Figure 2) ceased operations before the passage of the Maryland Strip Mining Bill in 1967. They are void of topsoil, and natural revegetation is progressing slowly. This natural recovery is seen in the continued decrease of the 1972 through 1974 satellite area measurements. The two Aaron Run mines are also revegetating. These mines were forfeited to the State unreclaimed prior to 1972. The State has backfilled and planted these areas, but the LANDSAT data indicates that reclamation has not been as successful as in other parts of the test site.

State records indicate 137 acres of coal were exposed and 157,000 tons of coal removed from the Mill Run-A mine (Figure 2) during the period monitored by the LANDSAT images. Aerial photography taken in October 1973 shows that the total affected area was 217.9 acres, 14.5 acres of which was partially reclaimed. The Sept. 73 LANDSAT classification identified 198.3 acres of unreclaimed area affected by surface mining, a 2.6% difference from the aerial interpretation. More reclamation had occurred by the time of the 1974 LANDSAT image which shows 191.7 acres in Mill Run-A. The 1972 LANDSAT image shows the full extent of the mine (222.1 acres) before reclamation.

Mill Run-B was opened in 1973. Prior to that the satellite data identified several pixels in the 1972 image in areas where roads had been cleared in preparation for strip mining. The 1973 aircraft and LANDSAT images indicate approximately 65 acres of land had been affected by stripping operations. The mine was backfilled and seeded during the next year, reducing the 1974 acreage to 53 acres.

The mines on Franklin Hill (Figure 2) were operative throughout the period covered by this investigation. High altitude photography of the region in 1972 and 1974 shows that these mines did not alter significantly in surface area over that period, even though 100 thousand tons of coal were extracted from these mines in 1973 alone. The Franklin Hill mines were opened before 1972 and the same areas have been restripped several times. The increased area identified in the 1974 LANDSAT image is due to new spoil piles and enlarged haul roads.

Figure 8 shows the band-ratio classifications applied to the same study area as Figure 6. The results demonstrate the geographic extendibility of the ratio signature. False-alarms are similar to those resulting from the 4-channel classification. Misclassifications of this sort are not generally serious since the locations of most of the mines are well known.

CONCLUSIONS

This study has demonstrated the feasibility of strip mine monitoring with LANDSAT multispectral data to within 2 hectares (5 acres). The average accuracy of classification is greater than 93% for LANDSAT images from three dates. Using band-ratioing techniques it is possible to extend signatures over a large geographic area and temporally to other LANDSAT images.

The procedures developed in this study could be incorporated into a comprehensive monitoring program to provide, in a rapid and inexpensive manner, accurate information on the location, size, and condition of areas affected by surface mining. Multispectral analysis of satellite digital data would be useful in validating operators' reports on the size and status of mining operations, locating abandoned and unrevegetated mines, and assessing reclamation costs and requirements.

REFERENCES

1. Board on Unreclaimed Strip Mined Lands, State of Ohio. Land Reborn, Jan. 1, 1974.

2. Council on Environmental Quality. Annual Report 1974.

3. Office of Enforcement, Environmental Protection Agency, An Application of ERTS Technology to the Evaluation of Coal Strip Mining and Reclamation in the Northern Great Plains. EPA-330/3-75-001; Feb. 1975.

4. Goetz, A.F.H. and Billingsley, F.C., "Digital Image Enhancement Techniques Used in Some ERTS Applications Problems", in Proceedings of the Third Earth Resources Technology Satellite-1 Symposium; Vol. I, Section A. NASA SP-351; 1974.

5. Kriegler, F.J., et al., "Preprocessing Transformation and Their Effects on Multispectral Recognition", in Proceedings of the Sixth International Symposium on Remote Sensing of the Environment. University of Michigan, Willow Run Laboratories, Ann Arbor, Michigan, October 1969.

TABLE II.- SURFACE AREA MEASUREMENTS FROM LANDSAT MSS 5/6 CLASSIFICATION AND LEAST SQUARES REGRESSION

Strip Mine	Aircraft Photography 10/16/73		LANDSAT Imagery											
			6 Sept. 72				1 Sept. 73				22 July 74			
	ha	acres	pixels	ha	acres	resid. ha	pixels	ha	acres	resid. ha	pixels	ha	acres	resid. ha
Mill Run-A[a]	88.2	217.9	204	89.9	222.1	1.7								
	82.4	203.4					182	80.3	198.2	-2.1	176	77.6	191.7	-4.8
Mill Run-B	22.8	56.4	6	(b)			59	26.2	64.7	3.4	48	21.4	52.9	-1.4
Aaron Run-A	12.7	31.4	34	15.2	37.5	2.5	30	13.5	33.3	0.8	23	10.4	25.7	-2.3
Aaron Run-B	18.8	46.4	42	18.7	46.2	-0.1	45	20.1	49.6	1.3	39	17.5	43.2	-1.3
Phoenix Hill-A	45.0	111.1	98	43.4	107.2	-1.6	95	42.0	103.7	-3.0	82	36.3	89.7	-8.7
Phoenix Hill-B	51.3	126.7	116	51.2	126.5	-0.1	115	50.9	125.7	-0.4	107	47.4	117.1	-3.9
Franklin Hill-A	98.7	243.8	224	98.8	244.0	0.1	230	101.4	250.4	2.7	239	105.4	260.3	6.7
Franklin Hill-B	42.7	105.5	91	40.3	99.5	-2.4	90	39.9	98.5	-2.8	99	43.7	107.9	1.0

[a]The acreage of Mill Run-A was reduced for '73 and '74 to exclude revegetated areas identifiable on the air photos.

[b]Mill Run-B was not opened until 1973.

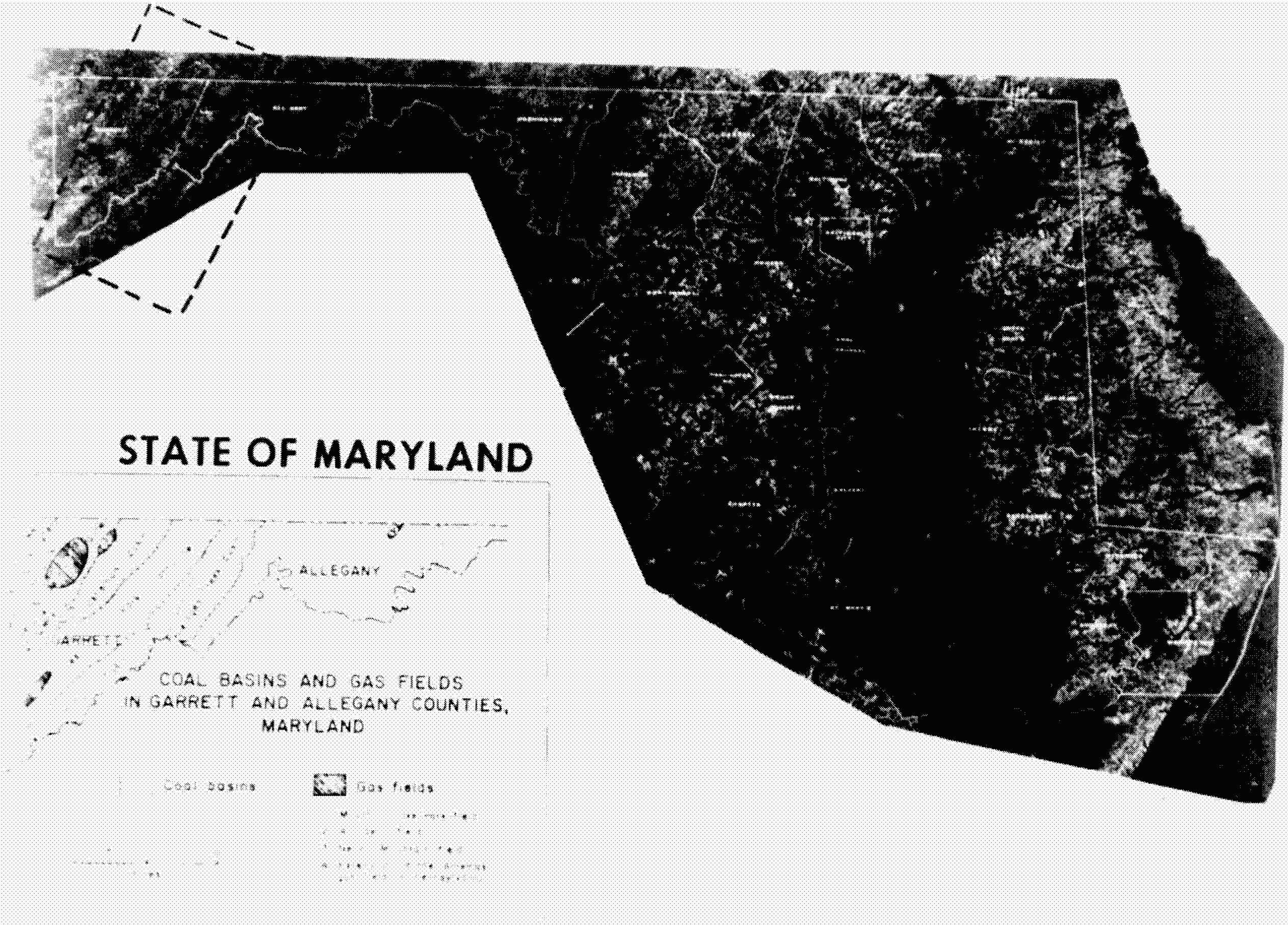


Figure 1. LANDSAT mosaic of Maryland with the test site and larger study region outlined; insert map of coal basins (from Vokes and Edwards, 1968).

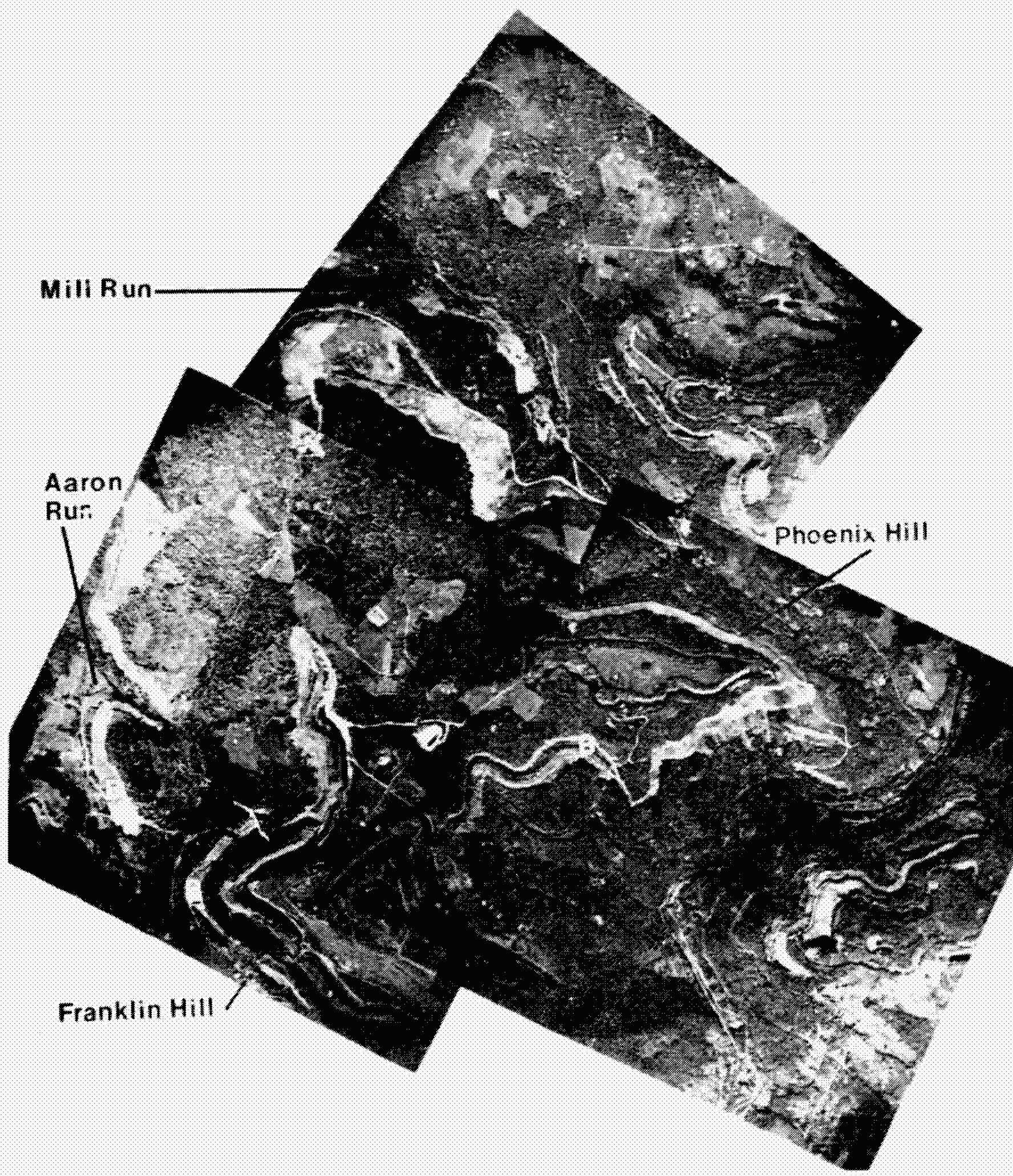


Figure 2. Low altitude NASA/Wallops aircraft photo-mosaic, taken 10/16/73, showing the 51.8 sq. km. test site with test strip mines identified.

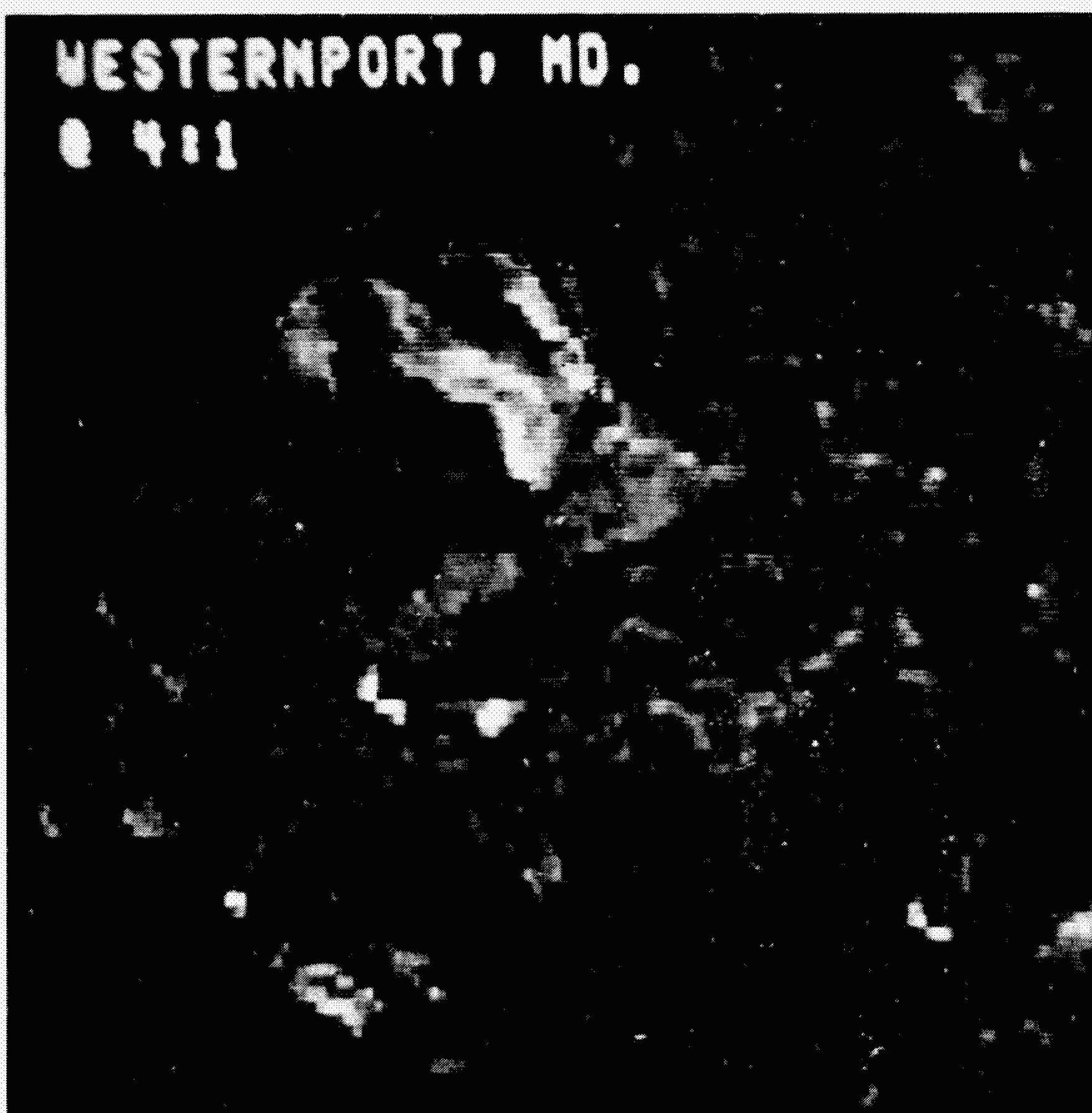


Figure 3. Computer output from video monitor showing test site from 1 September 1973 scene (1405-15242).

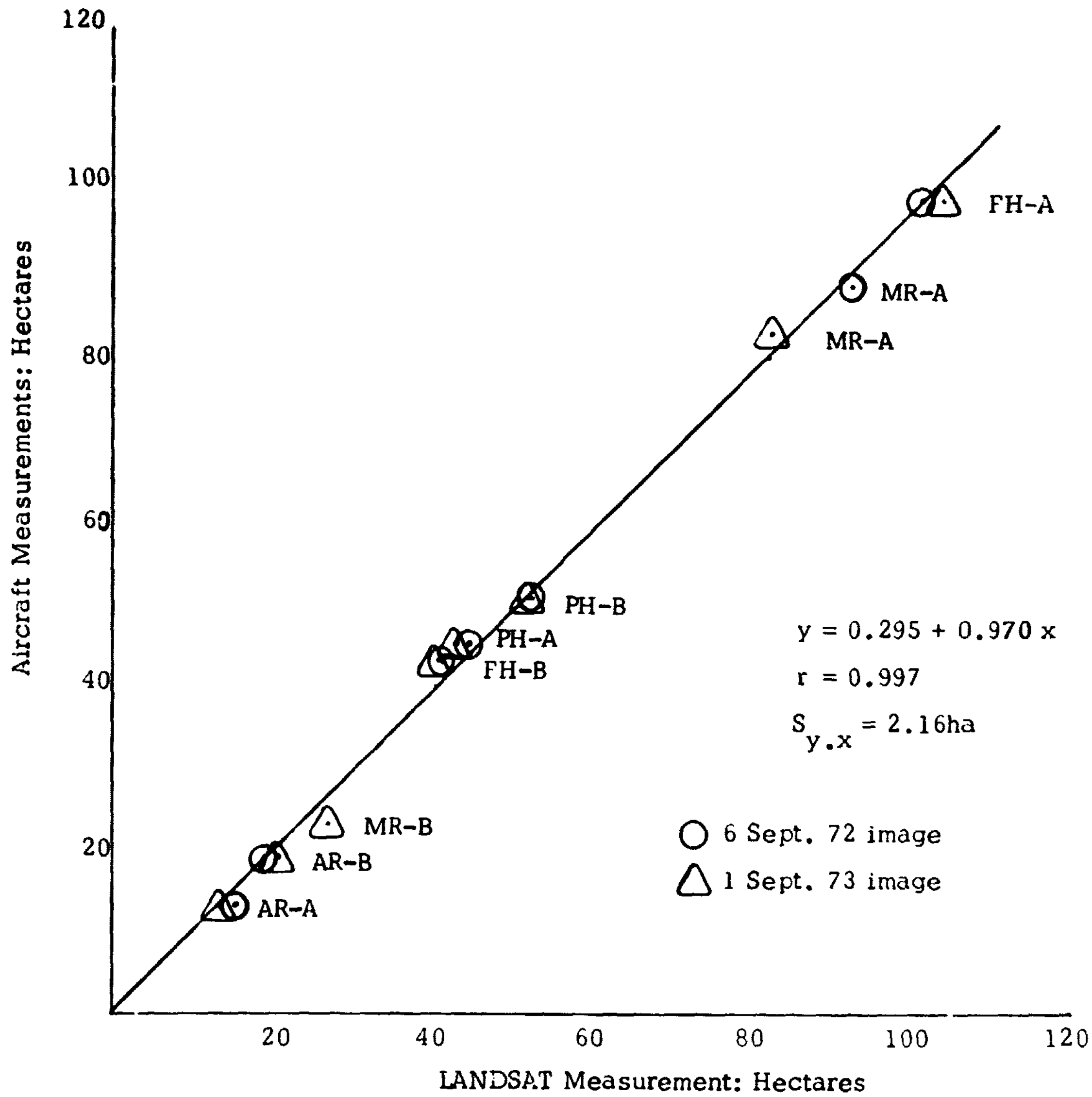


Figure 4.- Linear Regression Analysis of MSS 5/6 Strip Mine Classification

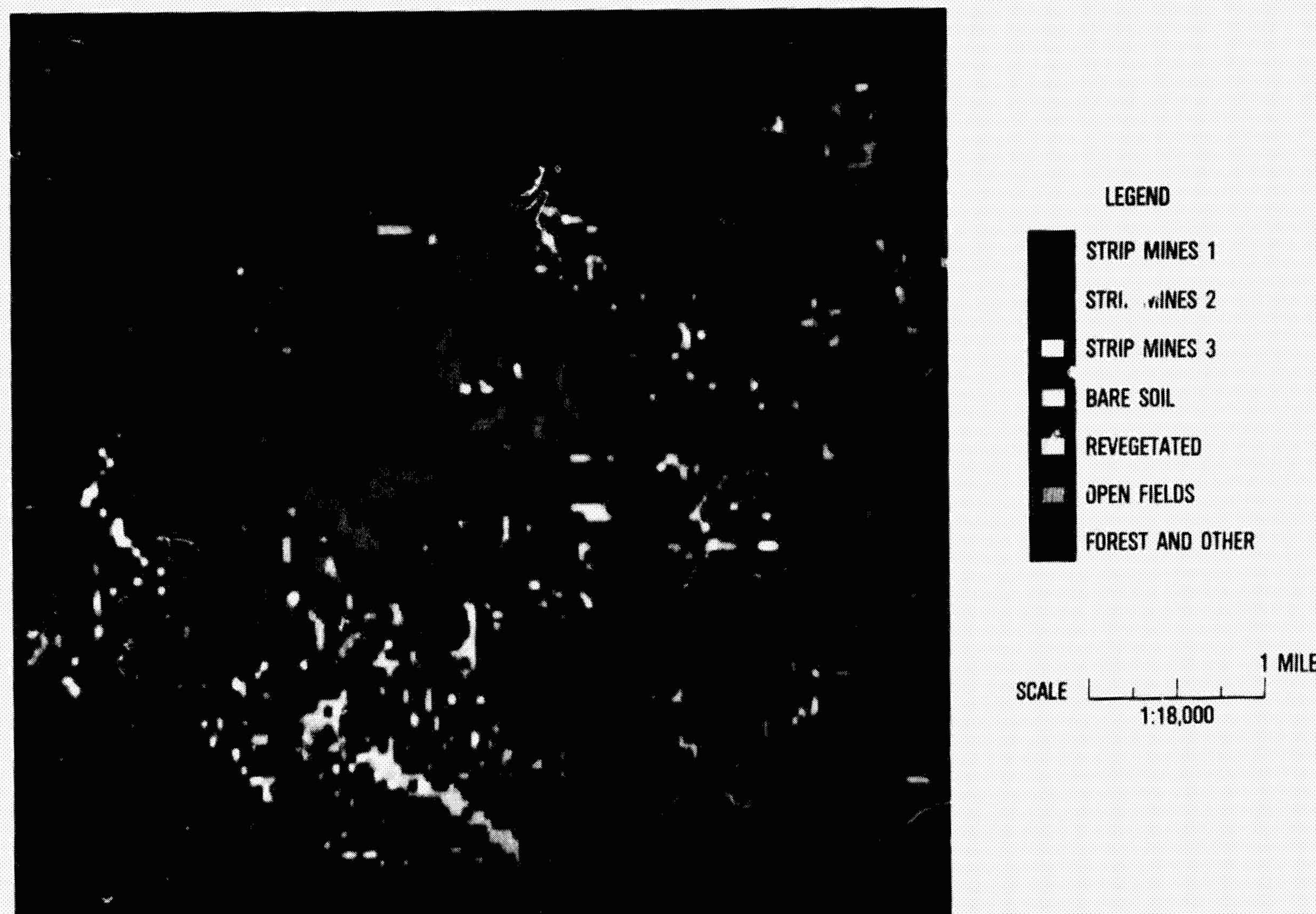


Figure 5. Interactive computer system output showing 4-band classification of test site.

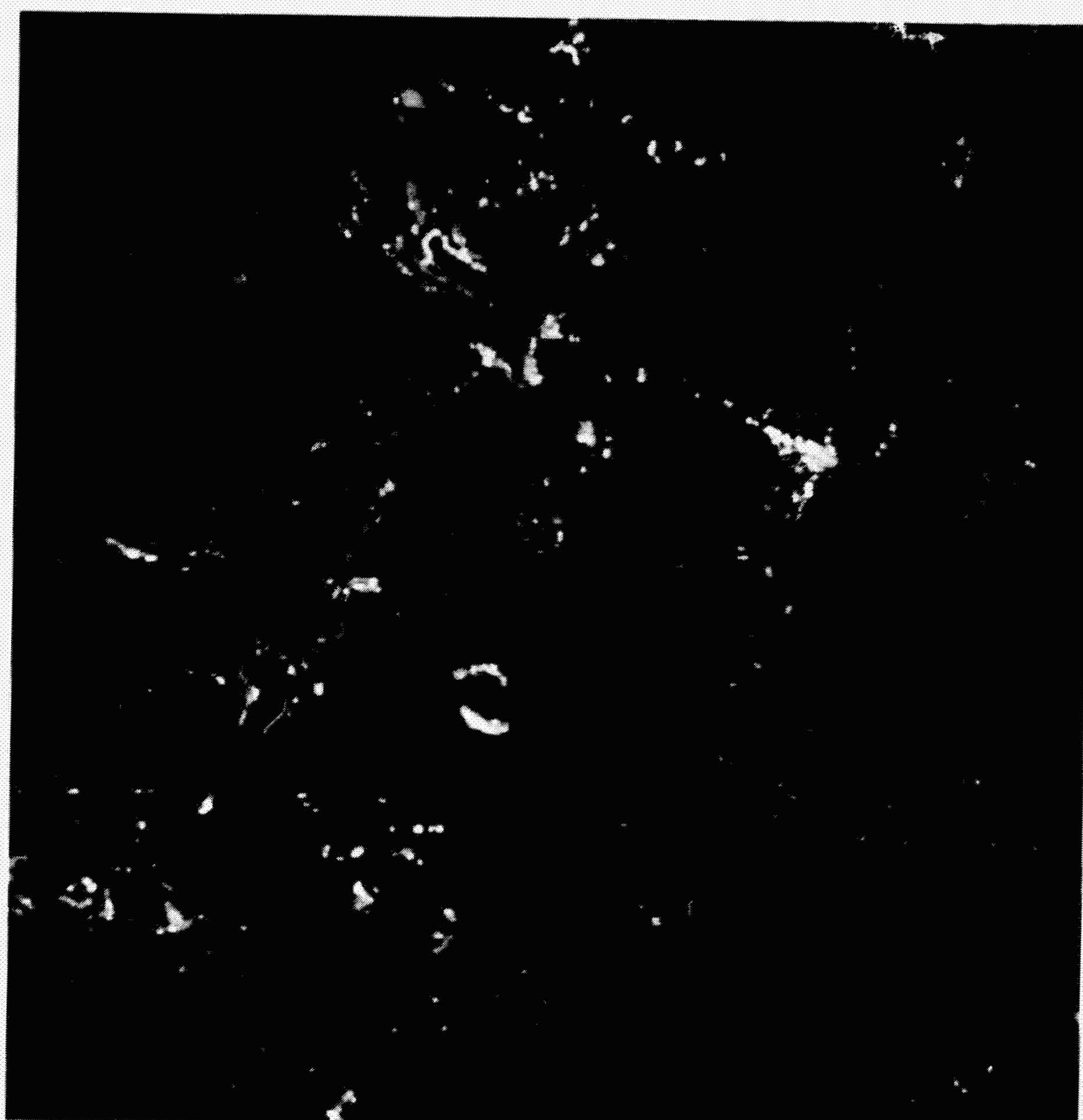
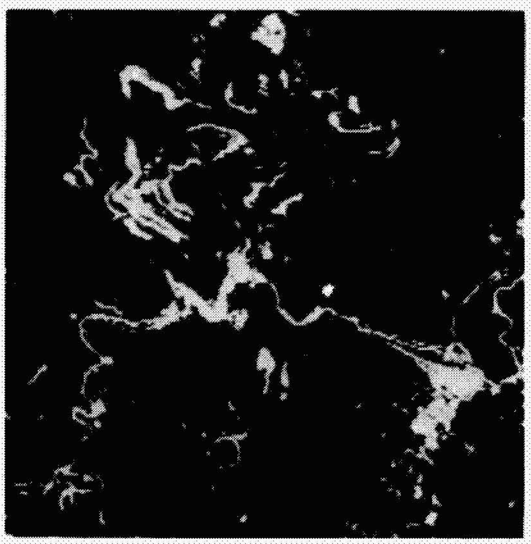
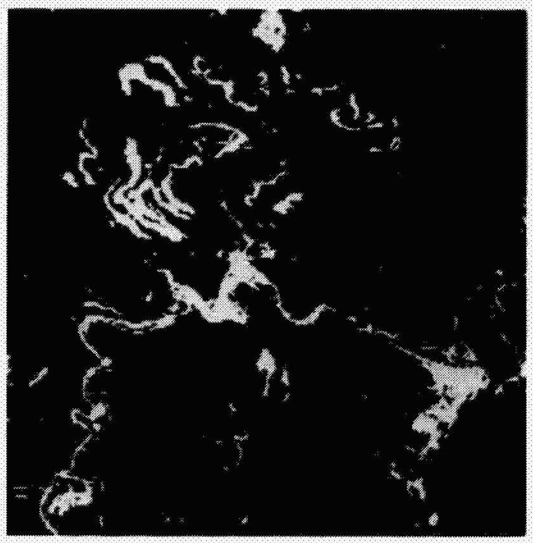


Figure 6. Four-band classification of strip mines and partially revegetated mines in entire study region.





(a) 6 September 1972

(b) 1 September 1973

(c) 22 July 1974

Figure 7. Strip mines identified on three LANDSAT images from same spectral signature in band 5/6 ratio.

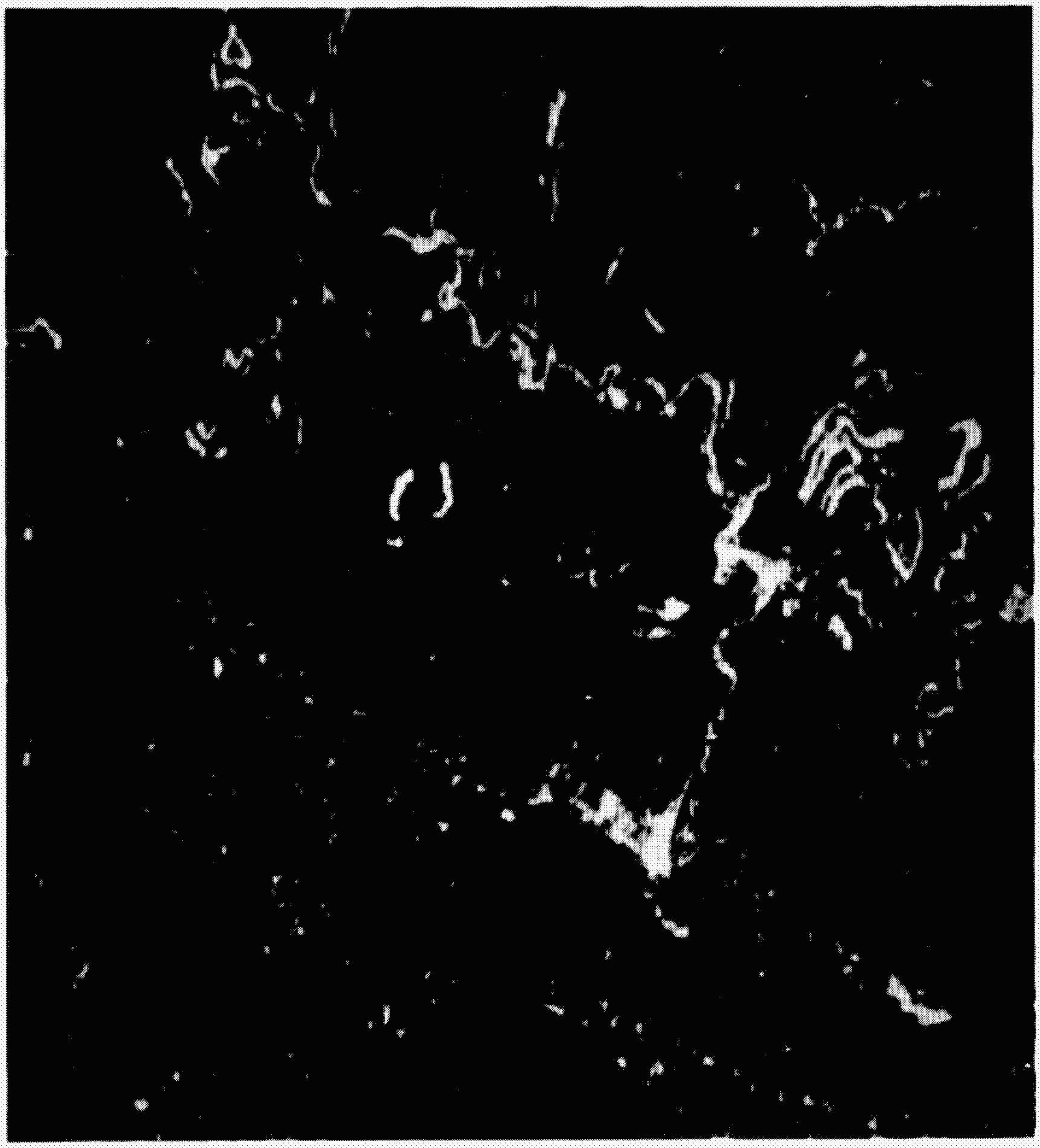


Figure 8. Band-ratio classification of strip mines for the study region, 1 September 1973.

QUANTITATIVE WATER QUALITY WITH LANDSAT AND SKYLAB* E-9

By Harold L. Yarger and James R. McCauley, University of Kansas, Lawrence, Kansas

N76-17493

ABSTRACT

LANDSAT Multispectral Scanner (MSS) reflectance levels are useful for quantitive measurement of suspended solids up to at least 900 ppm. MSS band ratios derived from computer compatible tape (CCT) can measure suspended solids with 67% confidence level accuracy of 12 ppm over the range 0-80 ppm and 35 ppm over the range 0-900 ppm. Suspended solids contour maps can be easily constructed from CCT's for water bodies larger than approximately 100 acres. Ratioing suppresses MSS reflectance level dependence on seasonal sun angle variation and permits measurement of suspended load the year round in the middle latitudes. These LANDSAT results are based on correlation studies between MSS CCT's and 170 water samples taken from three large Kansas reservoirs coincident with 16 different LANDSAT passes over a period of 13 months. SKYLAB imagery, S190A and S192, from a single pass over three reservoirs compares favorably to LANDSAT results up to 100 ppm. No samples were obtained with suspended solids greater than 100 ppm during the SKYLAB overpass. Typical mid-continent values for variables such as sun angle, wind speed and temperature do not significantly affect the correlation between satellite band ratios and suspended solids. The relatively high inorganic suspended solids, characteristic of mid-continent reservoirs, dominates the reflected energy present in the satellite spectral bands. Dissolved solids concentrations up to 500 ppm and algal nutrients up to 20 ppm are not detectable. The RED/GREEN ratio may have a weak negative correlation with total chlorophyll above ∿8μg/l.

INTRODUCTION

In the North American Great Plains, where natural permanent lakes are a rarity, the dominant limnological feature today takes the form of man-made reservoirs. The major reservoirs in Kansas, as well as in other Great Plains states, are playing increasingly important roles in flood control, recreation, agricultural and urban water supply and wildlife management. The primary influence on the reservoir ecosystem is the suspended load and chemicals carried in by streams and rivers. The reservoirs are typically shallow and thus are susceptible to mixing by strong winds which are a characteristic climatic feature of this region. Wind generated currents are of sufficiently high velocity to maintain a sizable fraction of the silts and clays in suspension and the result is turbid water (mean light extinction coefficient = 2.45 meter^{-1}). A method for acquiring timely low cost water quality data is needed to achieve optimum management of these fresh water resources.

A number of state and federal agencies in Kansas have expressed the need for repetitive water quality data such as suspended solids, dissolved solids, chlorophyll, and the algal nutrients. Some specific problems this data would apply to are discussed in the next several paragraphs.

The Forestry, Fish and Game Commission (FFGC) estimates that at least $18 million is spent annually by sport fisherman in Kansas. To help insure

*Work supported, in part, by NASA contracts NAS5-21822 and NAS9-13271

continued growth and good health for the sport fishing industry, the FFGC is interested in determining the effect of water environment on fish spawning and subsequent fish population. It is felt that the level of suspended solids significantly affects spawning and subsequent fish population. A knowledge of suspended load distribution in the lake would allow better fish management. Suspended load maps over a period of time would help to identify the best spawning areas within a reservoir and also would identify source points of undesirable high suspended load.

The Kansas State Health Department (KSHD) is concerned about the unpredictable occurrences of feedlot waste coming in contact with some of the city lakes used for drinking water. Feedlot waste usually contributes to the suspended load which is detectable by satellite. The KSHD is also concerned with chlorophyll and dissolved solids in the city lakes. The federal guideline of 500 PPM maximum allowable dissolved solids is often exceeded in the state of Kansas.

Temporal data on sediment load and source point location would allow better estimates of reservoir lifetime. Unusually high increases in sediment load/algal nutrients might permit timely identification of poor cultivation/fertilization practices upstream.

The goal of this study is to test the feasibility of using satellite imagery to monitor suspended load and chemical concentrations in Kansas reservoirs, which should be representative of most Great Plains reservoirs. This paper summarizes the contents of LANDSAT and SKYLAB contract final reports recently submitted to NASA (ref. 1,2). As work progressed on this project, a number of papers were presented at various symposia and subsequently published in proceedings (ref. 3-7). Figure 1 shows the distribution of the nineteen federal reservoirs in Kansas and the satellite ground traces used in this study. These reservoirs were built by the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation within the last 35 years. At normal pool elevation these water bodies have large surface areas relative to LANDSAT/SKYLAB resolution. The surface areas vary from about 3 square miles at Lovewell to about 25 square miles at Tuttle Creek. The shortest dimension of the main part of any of the reservoirs is approximately 1/2 mile. The largest dimension is about 20 miles. Depths vary from 40 to 50 feet at the dam to 1 to 2 feet at the upper end. Normal pool capacities vary from 10,000 to 500,000 acre-feet of water. In addition to the 19 major reservoirs there are approximately 100 smaller lakes in the state of Kansas with surface area greater than 20 acres as well as numerous stock ponds and ephemeral lakes which are detectable on LANDSAT and SKYLAB imagery.

The nineteen major reservoirs of Kansas are well distributed throughout the state occurring in a number of physiographic and land use regions that adequately represent much of the Great Plains environment. Lakes in extreme eastern Kansas lie within the humid portion of the state that is dominated by corn belt type agriculture. Lakes in central Kansas located within the Flint Hills and Smoky Hills escarpments collect drainage from important livestock grazing regions. Those reservoirs farther west in the semi-arid High Plains are in an important wheat and cattle producing area. Most of these lakes are operated by the Bureau of Reclamation and some are used for irrigation. Lakes in eastern Kansas are operated by the Corps of Engineers.

Two reservoirs, Perry and Tuttle Creek, were singled out for close study. Approximately ten water samples from each reservoir were collected during each cloud-free LANDSAT overpass for a 13 month period and analyzed for concentrations of inorganic suspended and dissolved solids, organic

suspended and dissolved solids, chlorophyll, potassium, phosphate, and nitrate ions. In addition, secchi disc and temperature measurements were taken at each sampling station. Wind velocity and lake level were also recorded. These two reservoirs are distinct in terms of the geology and land-use of their watersheds. Perry lies in the Corn Belt of Eastern Kansas in an area that was glaciated during the Kansas stage of Pleistocene glaciation. Tuttle Creek lies farther west in the northern portion of the Flint Hills and has a watershed underlain by Permian and Cretaceous rocks where livestock grazing and small grains production are important. Occasionally samples were collected from Milford Reservoir which lies 20 miles southwest of Tuttle Creek.

In addition to the relatively large amount of LANDSAT data, SKYLAB data from one pass (SL-3 September 18, 1973) was studied for correlation with water quality in three reservoirs in southeastern Kansas (see Figure 1 for location and size of reservoirs). S190A and B imagery was obtained for Toronto, Fall River and Elk City reservoirs. S192 CCT's were obtained for Elk City reservoir (the narrower S192 field of view missed the other two reservoirs). Water samples were collected from ten stations on each reservoir the same day as the SL-3 overpass.

LANDSAT DATA ACQUISITION AND REDUCTION

Ground truth and imagery were accumulated during the first 23 LANDSAT cycles over the state of Kansas. Of the 46 combined cycles over Perry and Tuttle Creek Reservoirs, 25 were cloud-free. Water samples (grab samples from first 30 cm. of water) were collected for 18 of the 25 cloud-free reservoir cycles. Conditions such as ice cover, high wind and mechanical failure prevented sample collection for the remaining 7 cloud-free cycles.

Four bands of MSS imagery in the form of 9-inch black-and-white positive transparencies were acquired for 15 of the 18 cloud-free cycles with ground truth. MSS computer compatible tapes (CCT's) were acquired for 16 of the 18 cloud-free cycles with ground truth.

The suspended and dissolved solids were determined using normal evaporation plus gravimetric procedures. Dissolved solids are defined as material surviving a 0.45 micron filter. The inorganic fraction of suspended and dissolved solids is defined as material that survived 1 hour at 600°C. Chlorophyll a, b and c concentrations were determined by acetonic extraction (ref. 8) and subsequent spectrophotometric measurement (ref. 9). Nitrate, phosphate and potassium concentrations were determined spectrophotometrically (ref. 10) on a Beckman DU Spectrophotometer.

Digital levels for each water sample were extracted from the CCT by locating the sample station coordinates on a CCT generated computer printout gray level map, then averaging 9 pixels centered around the coordinate which corresponds to a 240 x 240 meter square area on the water surface.

The water quality data along with secchi depth, temperature, lake level, wind speed and CCT digital levels were entered onto a disc file accessible by a time-sharing terminal. This data was used to search for quantitative correlation between MSS imagery and water quality parameters. The 9" positive transparencies for each MSS band were electronically sliced and displayed on our IDECS (Image Discrimination, Enhancement, and Combination System) system. The color coded displays were recorded on 35 mm film for permanent storage and further analysis. The level slicing was done on the basis of equal vidicon output voltage intervals which is equivalent to equal log density intervals. The maximum number of levels/ image was

determined by the dynamic range of the particular band over the reservoir surface and varied from 2 to 8 levels. The equal gray levels selected by IDECS correspond to nearly equal reflected energy intervals as defined on the NASA 15 step gray tablet. Maximum density variation (∿0.6 to 1.7) is usually found on the red band (MSS5) and corresponds to a power return range of 0 to ∿ 25%. The IDECS data was used as a qualitative guide in the study of quantitative correlation between water quality parameters and MSS CCT's.

SUN ANGLE EFFECTS

The multispectral scanner (MSS) in LANDSAT records light reflected from a scene illuminated by an admixture of sunlight and skylight (Figure 2). On relatively clear days the spectral shape of the illumination remains fairly constant throughout the year. However, the intensity, angle of incidence, and path length through the atmosphere depend on sun angle (angle above horizon). The reflectance levels from the concrete dam at Tuttle Creek Reservoir, a target with constant spectral reflectance, demonstrate a strong sun angle dependence in all MSS bands (Figure 3). As has been suggested by Vincent (ref. 11), the sun angle dependence is suppressed by plotting band ratios instead of absolute levels (Figure 4). The three other possible ratios, not plotted in Figure 4, also show a flat response to change in sun angle. Ratioing essentially removes the effect of unequal illuminating intensities caused by the continuously changing sun angle from one LANDSAT pass to the next. Since the ratio curves for the dam are flat, the angle of incidence and atmospheric scattering of reflected light are not important factors, at least for a concrete target.

Water reflectance levels do not exhibit as strong a dependence on sun angle, but there is a significant measureable effect (see Figure 5 for band 5 example). As for concrete, the absolute, reflectance levels for water decrease with lower sun angle. After ratioing (Figure 6) the three passes appear to be statistically similar. Dark object subtraction on each band before ratioing, as suggested by Vincent (ref. 11), does not significantly change the ratio curves in Figure 6. Dark object subtraction, which is the absolute level detected by LANDSAT minus level of darkest object in scene, should suppress atmospheric scattering effects present in the ratios.

These results suggest that the point scatter present in Figure 6 is not due to atmospheric scattering. For the remaining discussion it is assumed that, after ratioing, sun angle dependence and atmospheric scattering are relatively unimportant.

SUSPENDED SOLIDS

In general, bands 4, 5 and 6 (green, red, and near IR) exhibit substantial gray level variation across a reservoir surface. This gray level variation which is related to reflected energy detected by LANDSAT is highly correlated to the suspended sediment pattern in the reservoir. Bottom reflection is not a factor, because the reservoir bottom was not visible at any sample station. The subsequent discussion relates CCT digital levels (which are linearly proportional to reflected energy) to suspended load.

Band 4 shows no correlation beyond ∿ 50 ppm and is useful only for relatively clear water. This band (green) penetrates the water column more than the other bands (Figure 2), but as a consequence encounters a large amount of scattering material which produces saturation or maximum scattering at suspended solids levels (∿80 ppm) but its response to suspended load

is quite similar to band 4. Band 6 exhibits good correlation over the entire range 0 to 240 ppm. The band 7 reflection levels are very low, but still show some correlation with increasing suspended load.

As expected from the analysis in the previous section, band 5 ratioed with band 4 (Figure 7) improves suspended load correlation and is roughly linear in the range of 0 to 80 ppm with RMS residual of 12 ppm. All regression fits displayed in subsequent figures were done with horizontal axis as the dependent variable and vertical axis as the independent variable. The band 6 correlation is also improved by ratioing with band 4 (Figure 8). The MSS6/MSS4 ratio is linearly related to suspended solids in the region $\leq$ 100 ppm with an RMS residual of 19 ppm. The band 7 correlation, after ratioing with band 4, is not significantly improved.

Although the bulk of the suspended solids measurements were $\leq$240 ppm, there were a few (samples collected upstream in the reservoir after a recent rain) that extended as high as 900 ppm. The MSS5/MSS3 ratio rises sharply to $\sim$ 80 ppm then turns over and remains flat up to 900 ppm which is the limit of this investigation. The MSS6/MSS4 ratio (Figure 9) rises sharply to $\sim$ 120 ppm then turns over, but continues to correlate well with suspended solids up to 900 ppm. It appears that this correlation would continue well beyond 900 ppm. A smooth polynominal fit over the range 0-900 ppm yields an RMS residual of 35 ppm. Band 7/Band 4 (Figure 10) also shows correlation up to 900 ppm with an RMS residual of 44 ppm. The same third order fit to band 7 (not ratioed with another band) yielded an RMS residual of 46 ppm. Since band 7 is nowhere near maximum reflection at 900 ppm it is expected this band would continue to correlate up to extremely high suspended loads.

Table I summarizes the correlations between the three MSS ratios and suspended solids. The regression coefficients can be used to predict suspended load from CCT digital levels. MSS5/MSS4 is effective in the range 0-80 ppm with accuracy of 12 ppm. MSS6/MSS4 is effective in the range 0-120 or 0-900 ppm with accuracies of 19 and 35 ppm respectively. MSS7/ MSS4 is useful over the range 0-900 ppm with 44 ppm accuracy. It appears that the regression coefficients for MSS6/MSS4 and MSS7/MSS4 fits would be applicable substantially beyond 900 ppm, although this is not confirmed experimentally.

Figure 11 is an example of a suspended solids contour maps which was produced, in an earlier stage of this study, using regression coefficients that related band 5 to suspended solids. The coefficients were derived from four nearly equal high sun angle cycles which yielded an RMS residual of 5 ppm. In this particular case, ratioing was not required, since the correlation was based on nearly equal sun angle cycles.

SECCHI DEPTH

Analysis in the previous section establishes that suspended solids in water are strongly correlated with reflected energy present in the four MSS bands. Secchi depth (or water clarity) is inversely correlated with suspended solids measurements $\gtrsim$ 15 ppm which represents the bulk of the data in this study. Linear regression of suspended solids against inverse secchi depth yields an RMS residual of 18 ppm, so that a secchi depth measurement can be used to determine suspended load to this level of accuracy.

The MSS5/MSS4 ratio i [illegible] early correlated with secchi depth $\lesssim$ 0.6 meters (Figure 12), with RMS residual of 0.11 meters, which is merely a reflection of the fact that secchi depth is correlated with suspended

solids $\gtrsim$ 15 ppm. Beyond 0.6 meters ($\lesssim$ 15 ppm), where this ratio is not well correlated with suspended solids, the ratio correlation with secchi depth is much weaker, but still appears to decline slightly for increasing depths. MSS correlation with sunlight penetration depth in relatively clear ocean water has been found by other workers (ref. 12) and used to map ocean bottom to depths of 10 meters.

MSS6/MSS4 correlates with secchi depth down to $\sim$ 0.4 meters with RMS residual 0.06 meters (Figure 13). The correlation at shallow depth $\lesssim$ 0.2 meters is improved over the MSS5/MSS4 correlation. This is expected since this secchi depth range corresponds to suspended solids $\gtrsim$ 80 ppm where MSS5/MSS4 is poorly correlated. MSS7/MSS4 correlates with secchi depth up to $\sim$ 0.3 meters with RMS residual of 0.05 meters (not shown).

In summary, secchi depth correlates well with MSS ratios in relatively turbid water (suspended solids $\geq$ 15 ppm), but is primarily a reflection of the fact that secchi depth is correlated with suspended solids. Nevertheless, MSS ratios are useful for direct prediction of water clarity (secchi depth). Table II summarizes the results of the regression analysis.

WIND AND TEMPERATURE EFFECTS

An average wind velocity for each LANDSAT reservoir cycle was recorded along with a temperature measurement t each sample station. The three MSS ratios show no systematic correlation with wind speed (see Figure 14 for MSS5/MSS4 example) up to 21 miles/hour. As expected from previous laboratory work on distilled water (ref. 13), the MSS ratios exhibit no correlation with water temperature (Figure 15).

ORGANIC AND DISSOLVED SOLIDS

The character of the sediment carried into Tuttle Creek and Perry reservoirs can be summarized as follows. The lower part of the Blue River basin, which drains into Tuttle Creek, consists mainly of residual and alluvial soils derived from shales and limestones. The upper portion has loessial soils underlain by glacial tills and alluvial sands. The average particle size of the bottom sediment is 2 microns (ref. 14). The suspended sediment consists mostly of the three clays vermiculite, illite and kaolinite. Perry reservoir drains a basin consisting mostly of loessial soils underlain by glacial tills. Perry is generally not as turbid as Tuttle Creek, but its suspended sediment is very similar in mineralogy and degree of aggregation.

The following characterizes the composite sample set collected over a 13 month period from three reservoirs. The bulk of the samples contain total solids in the range 200 to 500 ppm. The suspended sediment fraction of the total solids ranges from 2 to 50%. The organic fraction of the suspended sediment is almost constant at 14% and is thus highly correlated with total suspended solids. Consequently, the MSS ratio correlation with organic suspended load (not shown) is merely a reflection of the MSS ratio dependence on total suspended load.

The dissolved solids fraction of total solids ranges from 50 to 98% which is, of course, the compliment of the suspended solids fraction. The organic fractions of dissolved solids range from 10 to 50%. The dissolved solids appear to be uncorrelated with suspended solids so that this experiment should be able to detect any appreciable influence dissolved solids

have on reflected energy levels in the MSS bands. However, MSS5/MSS4 does not show any obvious correlation with dissolved solids. The MSS6/MSS4 ratio also does not reveal any correlation with dissolved solids.

In summary, dissolved solids up to 500 ppm, whose mineralogic characteristics were discussed in the first part of this section, do not influence energy levels present in the four MSS bands.

CHLOROPHYLL AND ALGAL NUTRIENTS

Based on the anlysis presented earlier, it is obvious that MSS correlation with water quality parameters such as chlorophyll and the algal nutrients will be slight, if detectable at all.

The absorption peaks of chlorophyll a, b and c, which are 665mμ, 645mμ and 630mμ respectively, fall inside MSS band 5 (see Figure 2). The presence of chlorophyll, therefore, would cause an energy decrease in band 5. The characteristic green color of chlorophyll would cause an increase in band 4 energy which means the MSS5/MSS4 should be negatively correlated with chlorophyll.

Total chlorophyll appears to be largely uncorrelated with suspended sediment (plot now shown), so any appreciable effect concentrations up to 20μg/l have on MSS ratios should be detectable. The MSS5/MSS4 shows no obvious correlation with the composite 13 month sample collection. The subset of samples, whose suspended load (>80 ppm) causes no variation in the MSS5/MSS4 ratio, also does not show any significant negative correlation with chlorophyll.

The residual MSS5/MSS4 ratio, obtained by removing the linear ratio dependence on suspended solids for samples with <80 ppm suspended load, is shown in Figure 16. As can be seen, a slight negative correlation with total chlorophyll may be setting in for chlorophyll concentrations $\gtrsim$8μg/l. Chlorophyll a, b and c were studied individually with results consistent with those for total chlorophyll. In each case, the 3 to 6 samples with highest concentration appeared to have a slight negative correlation with MSS5/MSS4.

In summary, typical chlorophyll levels in Kansas reservoirs of 0 to 8μg/l are not detectable by LANDSAT. There does seem to be a slight negative correlation with MSS5/MSS4 beyond 8μg/l but there are not enough samples to determine a reliable quantitative correlation. Other workers (ref. 15) have found that LANDSAT is able to detect chlorophyll at $\sim$10μg/l concentration in relatively clear seawater. In our case, the noise from the relatively high turbidity is probably masking the chlorophyll signal from Kansas reservoirs.

Concentrations of potassium, phosphate and nitrate were studied for possible influence on reflected energy levels present in the four MSS bands. The results were negative except for some MSS ratio correlation with phosphate. This is due, however, to the fact that phosphate is somewhat correlated with suspended solids. In summary, the algal nutrients potassium, phosphate and nitrate at concentration levels up to 20, 2 and 10 ppm respectively are not correlated with LANDSAT imagery.

CCT'S VS. POSITIVE TRANSPARENCIES

Densitometer measurements were made of reservoir images and the accompanying gray-step scale at the bottom of each image. The gray steps are

linearly related to CCT levels so that density measurements can be directly converted to an equivalent CCT levels. An example is shown in Figure 17. CCT and density values compare quite favorably thus indicating that density measurements should produce quantitative results comparable to those obtained using CCT's.

In Figure 18 IDECS levels are compared with digital tape levels for a cycle over Perry Reservoir. IDECS levels were normalized to the CCT levels by matching the lowest and highest IDECS levels to the lowest and highest CCT levels repsectively. As seen in Figure 18 the two methods of analysis compare favorably. Other cycles produced equally favorable results. In general, IDECS levels, once normalized to CCT levels agree well with CCT levels. However, IDECS levels, which are gray levels obtained from 9" transpar is are not useful in an absolute sense. IDECS levels are useful for qualitatively displaying relative suspended load distribution in a reservoir. IDECS levels are not related to a standard scale, as are the CCT levels, so are not as useful quantitatively.

SKYLAB IMAGERY

SKYLAB imagery was obtained for one SL-3 pass over southeastern Kansas. This imagery consists of S190A and B film and S192 CCT's. The S190A is in the form of 70 mm and 4X enlarged positive transparencies of the four bands green, red, IR_1 and IR_2 (see Figure 2 for band widths) and covers the three reservoirs Toronto, Elk City and Fall River (see Figure 1). The S190B is 5" aerial color over the same three reservoirs. The S192 CCT covers Elk City Reservoir only.

The superior resolution of S190B provides an excellent qualitative "first look" at turbidity patterns. This imagery will not, however, provide quantitative information on suspended solids. The S190A 70 mm transparencies were measured on a macrodensitometer with a 1 mm aperture. The small size of the reservoirs on 70 mm film permitted only one density measurement per reservoir. The densities were converted to absolute radiance levels using SL-3 sensitometric data (ref. 16) provided by NASA. The radiance levels are plotted against average suspended solids for each reservoir (Figure 19). The shaded areas in Figure 19 represent LANDSAT radiance levels for about 60 water samples from 7 passes with comparable sun angles. The agreement between S190A and LANDSAT in the three bands green, red and IR is quite good.

Digital level maps from S192 CCT's for Elk City reservoir were generated for the three bands shown in Figure 19. Nine pixels were averaged at each measurement station and converted to an absolute radiance level using the calibration coefficients on the CCT header record. The radiance levels for each station are shown as solid points in Figure 19. S192 green represents an average of band 3 and 4 (see Figure 2 for equivalent S192 green band width). The agreement between SKYLAB S192 and LANDSAT MSS is poor, fair and good respectively in the three bands green, red and IR. The poor agreement in the green band may be due to the fact that the band widths for S192 green and LANDSAT green are not an exact match.

SKYLAB band ratios vs. suspended solids are shown in Figure 20. All ratios, except perhaps S192 red/green, are consistent with linear fits to LANDSAT ratios.

The S190A 4X enlargements permitted density measurements of individual measurement stations on each reservoir. We have been unable to obtain the sensitometric data required to relate density on the enlargements to abso-

lute radiance. However, if the reservoir densities are in the linear region of the density vs. log(exposure) curve for the film, then the radiance ratio can be written as

$$\frac{Ei}{Ej} = k \frac{10^{-Di}}{10^{-Dj}}$$

where Ei and Ej are band i and j radiances from the target and Di and Dj are corresponding film densities. K is a constant determined by the slope of the D vs. logE curve which relates the density of our film copy to the original exposure on SKYLAB. K also depends on filter and camera lense attenuation coefficients, shutter speed, etc. This constant has not yet been determined but is arbitrarily set = 1 in Figure 21. The absolute ratio values cannot be compared to S192 or LANDSAT because of the lack of sensitometric calibration data. The red to greed band ratio (Figure 21) exhibits a good linear correlation with suspended solids (RMS residual of 6 ppm). Beyond 80 ppm the LANDSAT MSS red/green ratio flattens out. We would expect the SKYLAB S190A red/green ratio to also flatten out, but the relatively clear water sampled does not permit confirmation of this.

In summary, the small amount of data available from the S190A and S192 is in general quantitatively consistent with water reflectance levels measured by the LANDSAT MSS sensor. It appears that S190A is superior to S192 for the purpose of predicting suspended solids in water. More data is needed to confirm this single pass result.

CONCLUSIONS

LANDSAT MSS ratios derived from CCT's are very effective for quantitative detection of suspended solids up to at least 900 ppm, which is the limit of this investigation. The actual upper limit on suspended solids LANDSAT can detect is probably substantially higher. Typical mid-continent values for variables such as sun angle, wind speed and temperature do not significantly affect MSS ratios.

Dissolved solids up to at least 500 ppm are not correlated with LANDSAT imagery. The algal nutrients potassium, phosphate and nitrate at concentration levels up to 20, 2 and 10 ppm respectively are not correlated with LANDSAT imagery. The MSS5/MSS4 ratio appears to be weakly correlated with total chlorophyll above concentration levels of $\sim 8 \mu g/l$, but more data are needed to confirm this.

Density measurements from the NASA 9" positive transparencies compare favorably with CCT levels. It would be relatively simple and inexpensive for interested agencies or groups to obtain suspended load information by using a macrodensitometer.

A small amount of data from the SKYLAB sensors S190A and S192 is consistent with LANDSAT results. S190A appears to do a superior job compared to S192 in measurement of suspended solids. Both sensors are probably as effective as the LANDSAT MSS for measuring suspended solids in water.

REFERENCES

1. Yarger, Harold L. and James R. McCauley, "Monitoring Fresh Water Resources," Type III Final Report, March 24, 1974. Available from NTIS.

2. Yarger, Harold L. and James R. McCauley, "SKYLAB Study of Water Quality," Final Report to NASA, July, 1975. Available from NTIS.

3. Yarger, H. L., J. Coiner, G. James, L. Magnuson, J. McCauley, and G. Marzolf, (1972), "ERTS-1 Study of Reservoirs in Kansas," Proceedings of the Eighth International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, Vol. 2, 1477.

4. Yarger, H. L., J. R. McCauley, G. W. James, L. W. Magnuson, and G. R. Marzolf, (1973), "Water Turbidity Detection Using ERTS-1 Imagery," Proceedings of Symposium on Significant Results Obtained From the Earth Resources Technology Satellite-1, Goddard Space Flight Center, vol. 1, p. 651.

5. McCauley, J. R., H. L. Yarger, G. W. James, L. Magnuson, and G. Marzolf, (1973), "ERTS-1 Reservoir Monitoring Studies in Kansas," Proceedings of the Symposium on the Remote Sensing of Water Resources, Canada Centre for Inland Waters, Burlington, Ontario.

6. Yarger, H. L., J. R. McCauley, G. W. James, L. Magnuson, and G. Marzolf, (1973), "Quantitative Water Quality with ERTS-1," Proceedings of the Third ERTS-1 Symposium, Goddard Space Flight Center, Vol. I: Section B, p. 1637.

7. McCauley, James and Harold Yarger, (1975), "Kansas Water Quality Using ERTS-1," to be published in Proceedings of the Fourth Annual Remote Sensing of Earth Resources Conference, The University of Tennessee Space Institute, Tallahoma, Tennessee.

8. Richards and Thompson, (1952), J. Marine Res., 2, 156.

9. Vollenweider, Richard A. (1969), A Manual on Methods for Measuring Primary Production in Aquatic Environments, F. A. Davis Co., Philadelphia.

10. "Standard Methods for the Examination of Water and Wastewater," (1965), 12th Ed., American Public Health Association, Inc., New York, N. Y., pp. 200-202, 321-232.

11. Vincent, Robert K., (1972), "An ERTS Multispectral Scanner Experiment for Mapping Iron Compounds": Proceedings of the Eighth International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, Oct. 2-6, pp. 1239-1243.

12. Polcyn, F. C. and D. R. Lyzenga, (1973), "Calculations of Water Depth from ERTS-MSS Data," Proceedings of Symposium on Significant Results Obtained from the ERTS-1 Satellite Goddard Space Flight Center, Vol. I, Section B, p. 1433.

13. Scherz, James P., (1971), "Monitoring Water Pollution by Remote Sensing," Journal of the Surveying and Mapping Division, ASCE, vol. 97, no. SU2, Proc. Paper 8550, pp. 307-320.

14. Schwartz, J. M., and G. R. Marzolf, (1971), "Sediment Character and Distribution in a Great Plains Reservoir," Trans. Kansas Acad. of Science, V. 74, p. 59-66.

15. Szekielda, K-H, and Robert J. Curran, (1973), "Biomass in the Upwelling Areas along the Northwest Coast of Africa as Viewed with ERTS-1": Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1, Goddard Space Flight Center, March 5-9, pp. 651-658.

16. "SL-3 Sensitometric Data Package," Report no. JL12-503, November 23, 1973.

TABLE 1. RESULTS OF FITTING SUSPENDED SOLIDS MEASUREMENTS TO CCT MSS BAND RATIOS. EQUATION USED IN FIT WAS $SS = a_0 + a_1 R_{ij} + a_2 R_{ij}^2 + a_3 R_{ij}^3$ WHERE SS = SUSPENDED SOLIDS (PPM) AND R_{ij} = (BAND$_i$ AVERAGE CCT LEVEL FOR 9 PIXELS)/(BAND$_j$ AVERAGE CCT LEVEL FOR 9 PIXELS).

MSS BAND RATIO	RANGE OF APPLICABILITY IN PPM	RMS RESIDUAL IN PPM	$a_0 \times 10^{-2}$	$a_1 \times 10^{-2}$	$a_2 \times 10^{-2}$	$a_3 \times 10^{-2}$
R_{54}	0-80	12	-0.793	1.387	-	-
R_{64}	0-120	19	-0.426	1.768	-	-
R_{64}	0-900	35	-6.403	42.598	-89.112	62.373
R_{74}	0-900	44	0.090	5.580	-43.879	254.654

TABLE 2. RESULTS OF FITTING SECCHI DEPTH MEASUREMENTS TO CCT MSS BAND RATIOS. EQUATION USED IN FIT WAS $SD = a_0 + a_1 R_{ij}$ WHERE SD = SECCHI DEPTH (METERS) AND R_{ij} = (BAND$_i$ AVERAGE CCT LEVEL FOR 9 PIXELS)/(BAND$_j$ AVERAGE CCT LEVEL FOR 9 PIXELS).

MSS BAND RATIO	RANGE OF APPLICABILITY IN METERS	RMS RESIDUAL IN METERS	a_0	a_1
R_{54}	0-0.70	0.11	1.210	-1.061
R_{64}	0-0.40	0.06	0.526	-0.529
R_{74}	0-0.30	0.05	0.278	-0.727

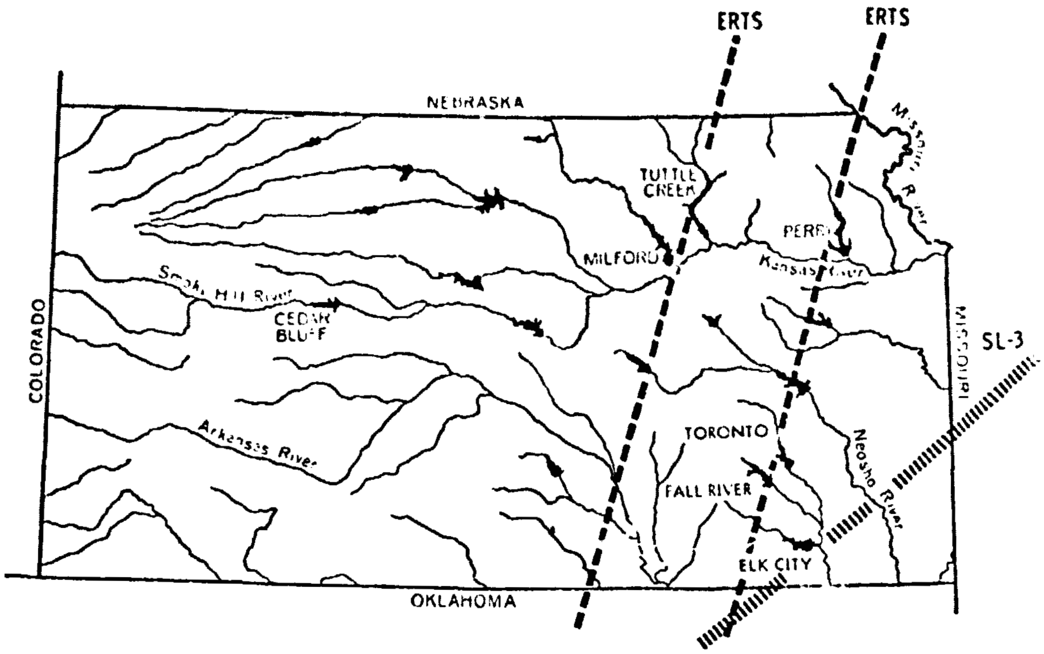


FIGURE 1. LANDSAT AND SKYLAB 3 GROUND TRACKS IN KANSAS.

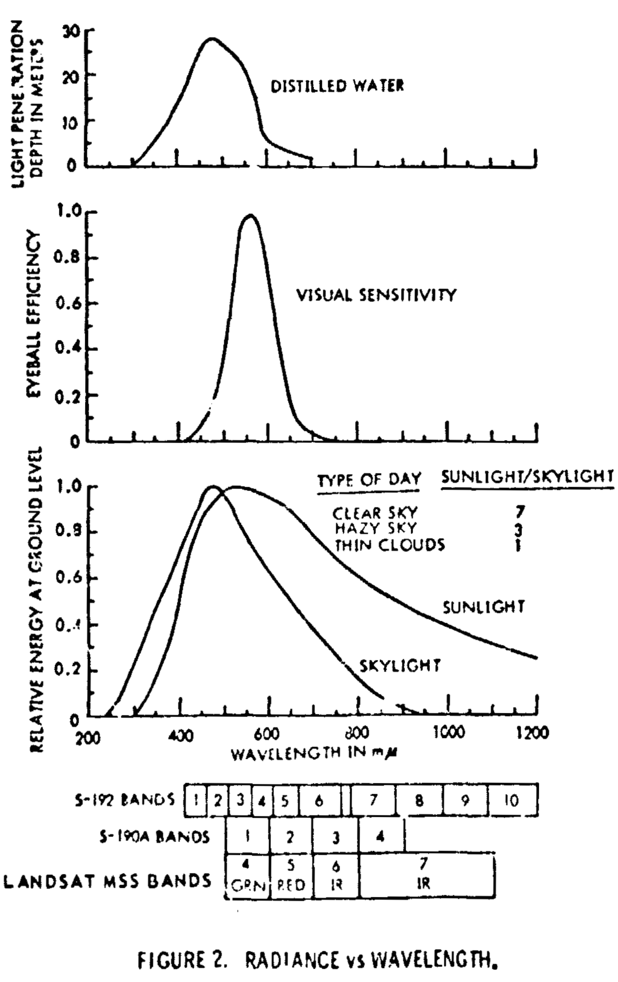


FIGURE 2. RADIANCE vs WAVELENGTH.

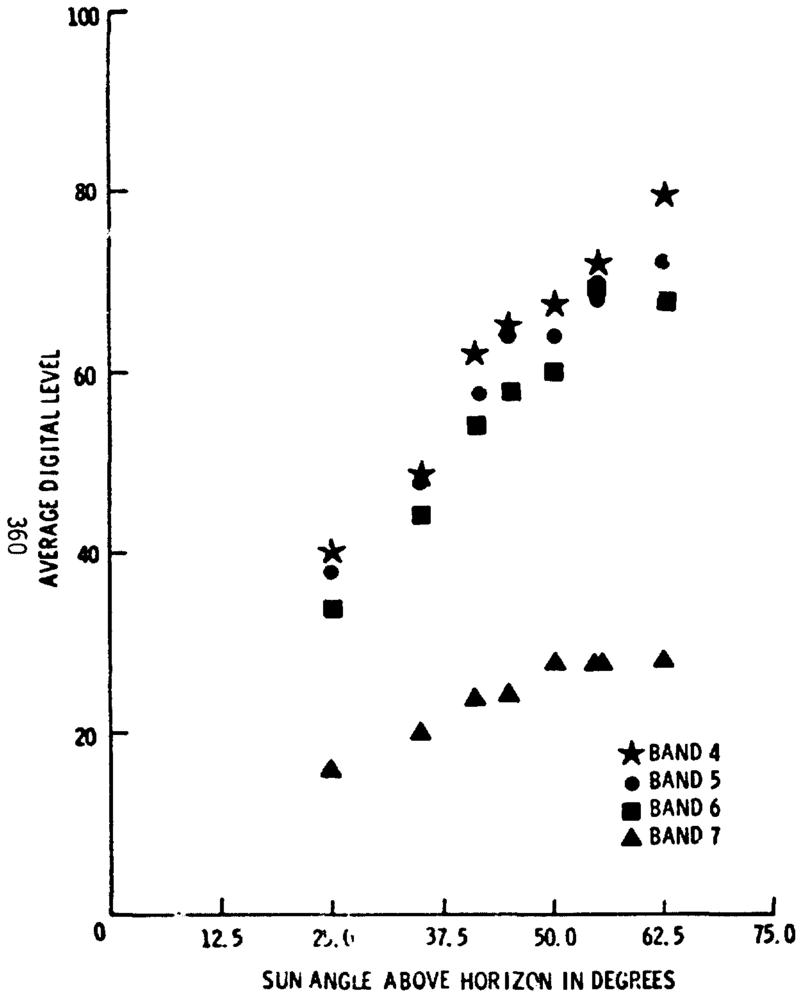


FIGURE 3. MSS DIGITAL LEVELS FROM CCT VS. SUN ANGLE FOR TUTTLE CREEK CONCRETE DAM.

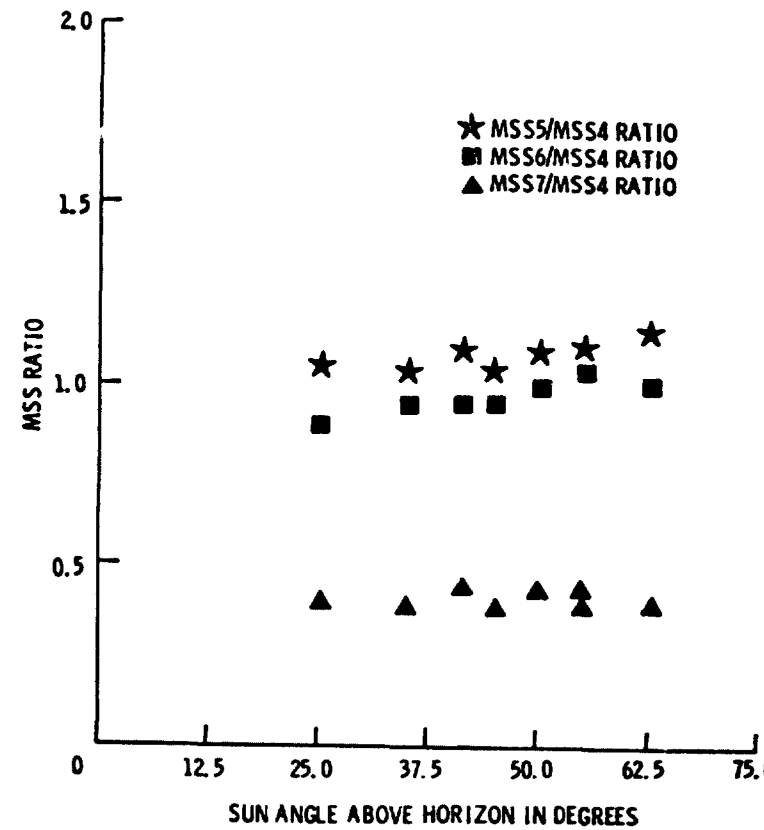


FIGURE 4. MSS BAND RATIOS FROM CCT VS. SUN ANGLE FOR TUTTLE CREEK CONCRETE DAM.

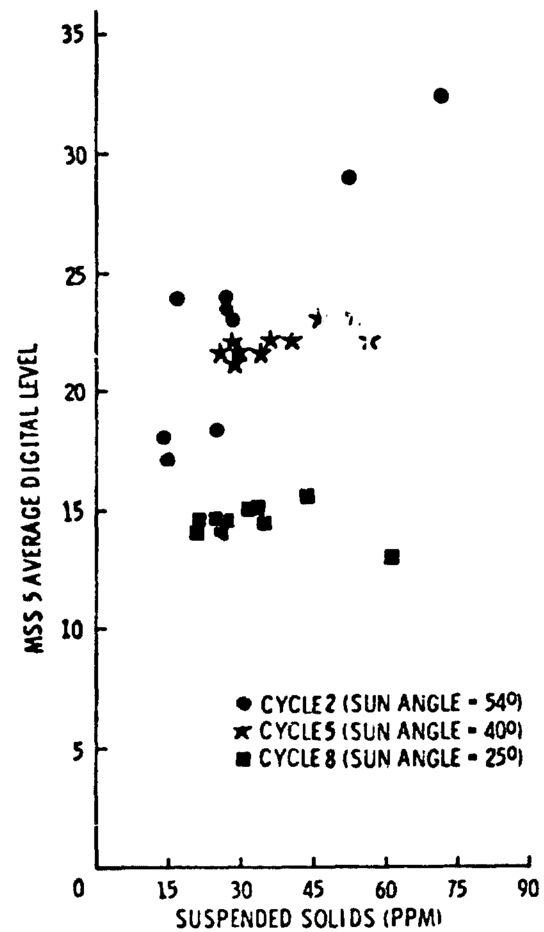


FIGURE 5. MSS5 DIGITAL LEVELS FROM CCT VS. SUSPENDED SOLIDS FOR 28 WATER SAMPLES FROM 3 LANDSAT-1 CYCLES.

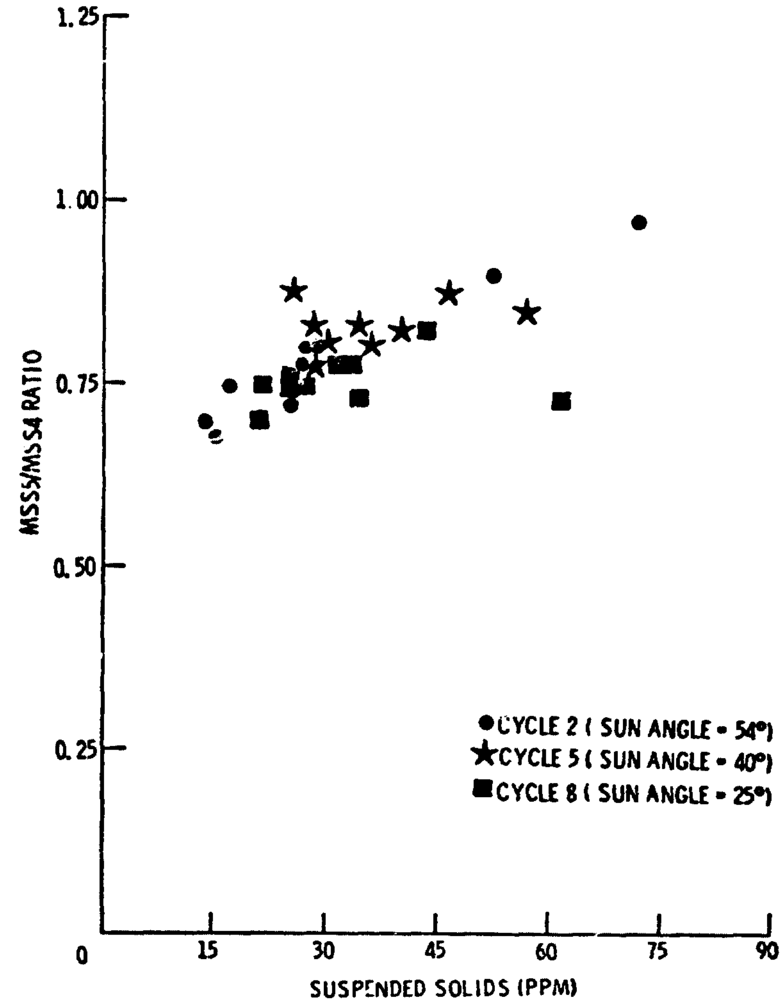
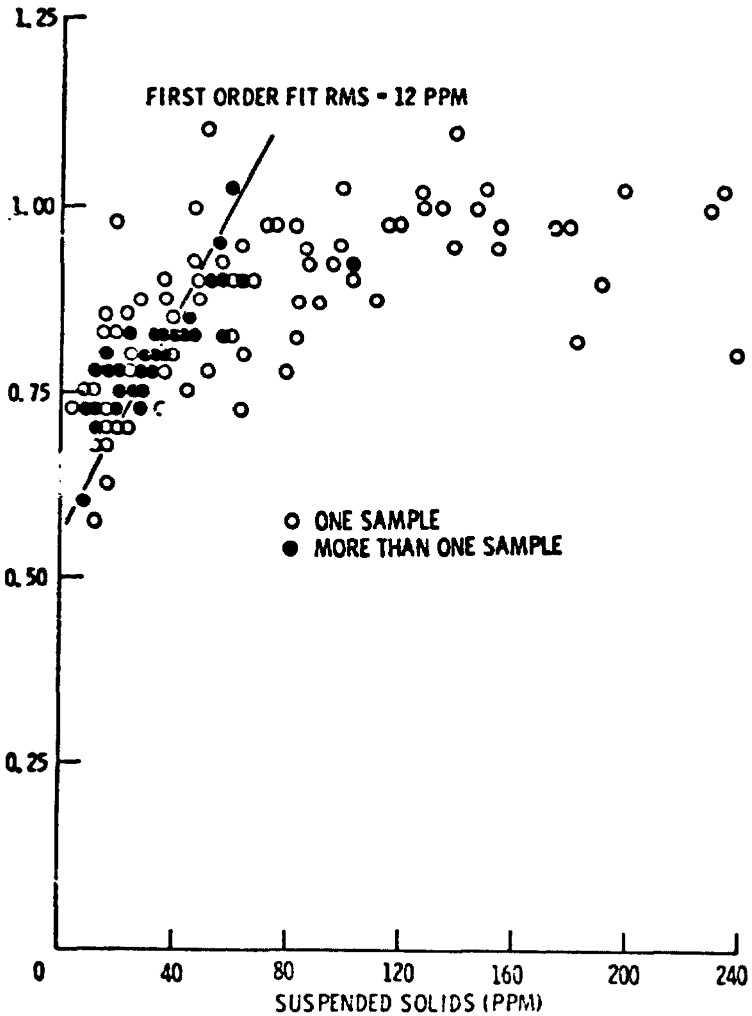


FIGURE 6. MSS5/MSS4 RATIO FROM CCT VS. SUSPENDED SOLIDS FOR 28 WATER SAMPLES FROM 3 LANDSAT-1 CYCLES.



F..URE 7. MSS 5/MSS 4 CCT RATIO VS. SUSPENDED SOLIDS FOR 167 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT LANDSAT-1 CYCLES.

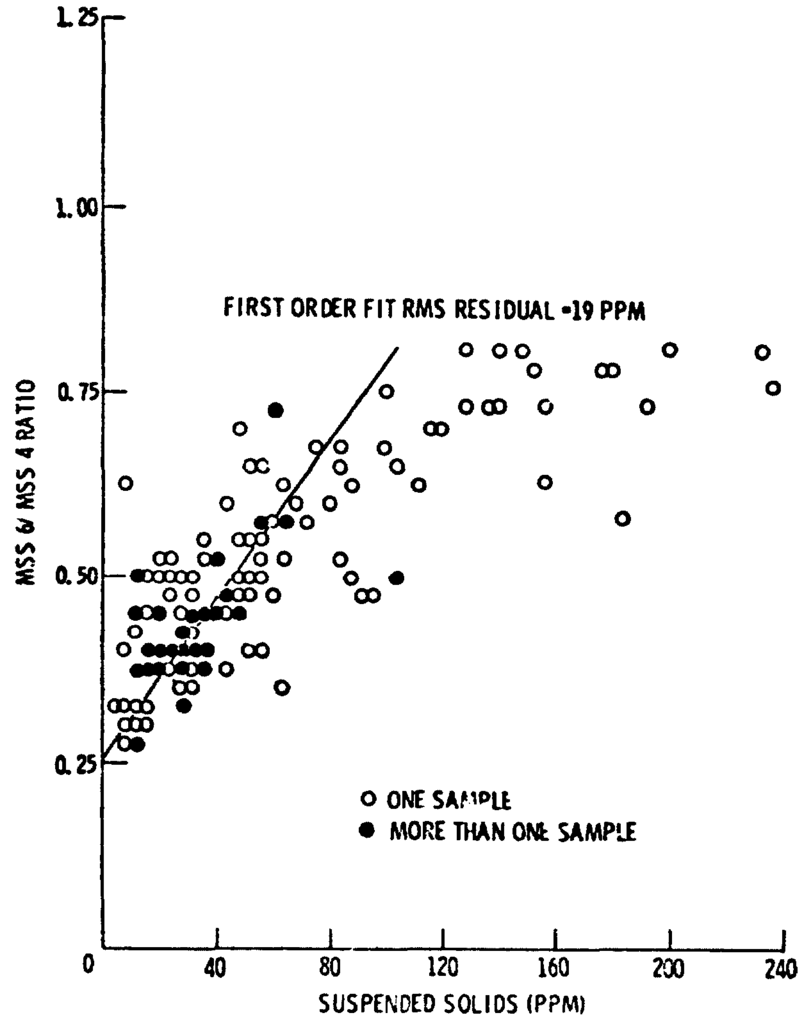


FIGURE 8. MSS6/MSS 4 CCT RATIO VS. SUSPENDED SOLIDS FOR 166 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT LANDSAT-1 CYCLES.

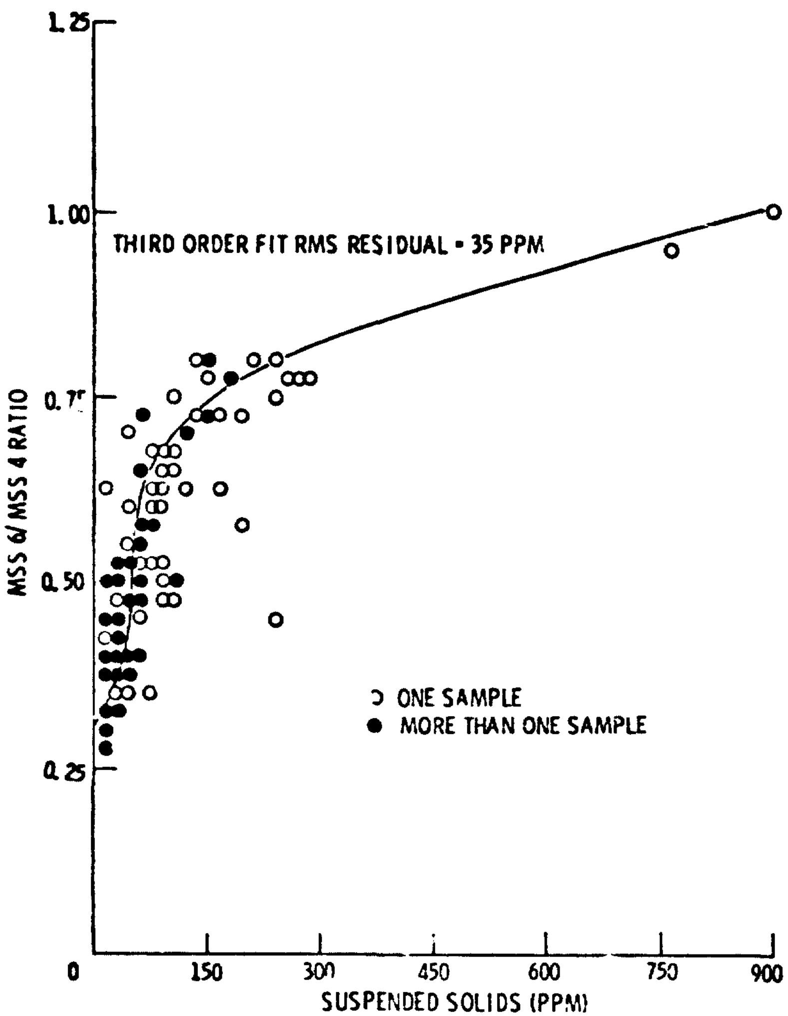


FIGURE 9. MSS 6/MSS 4 CCT RATIO VS. SUSPENDED SOLIDS FOR 170 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT LANDSAT-1 CYCLES.

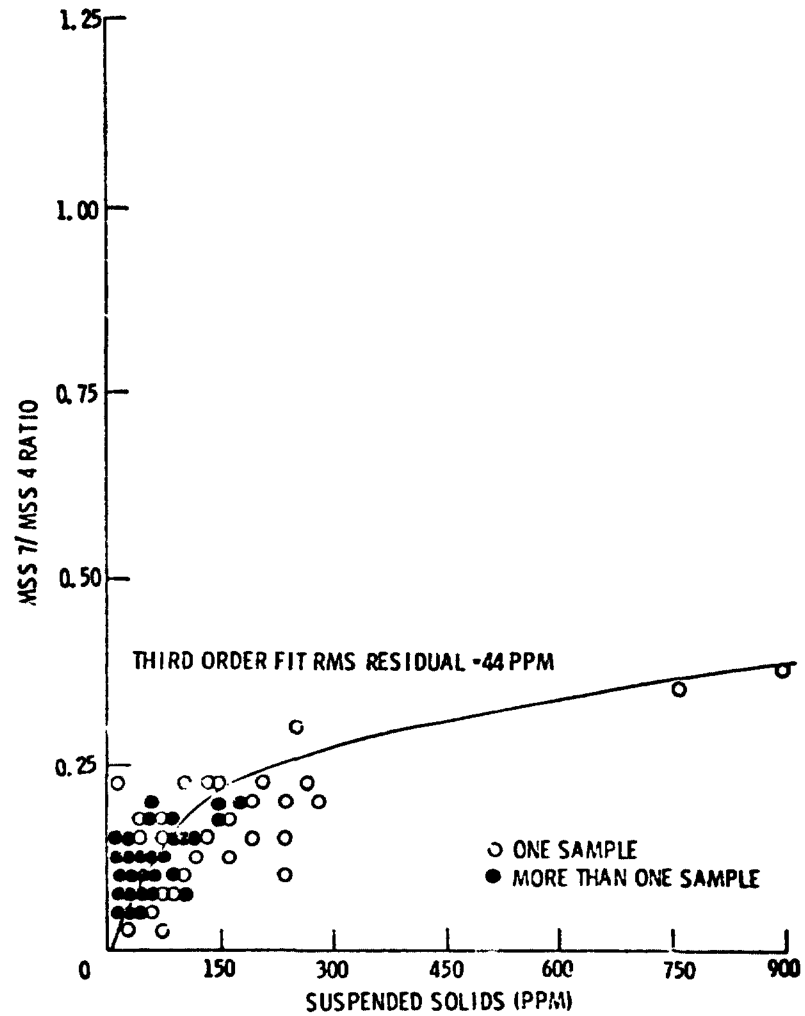


FIGURE 10. MSS 7/MSS 4 CCT RATIO VS. SUSPENDED SOLIDS FOR 171 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT LANDSAT-1 CYCLES.

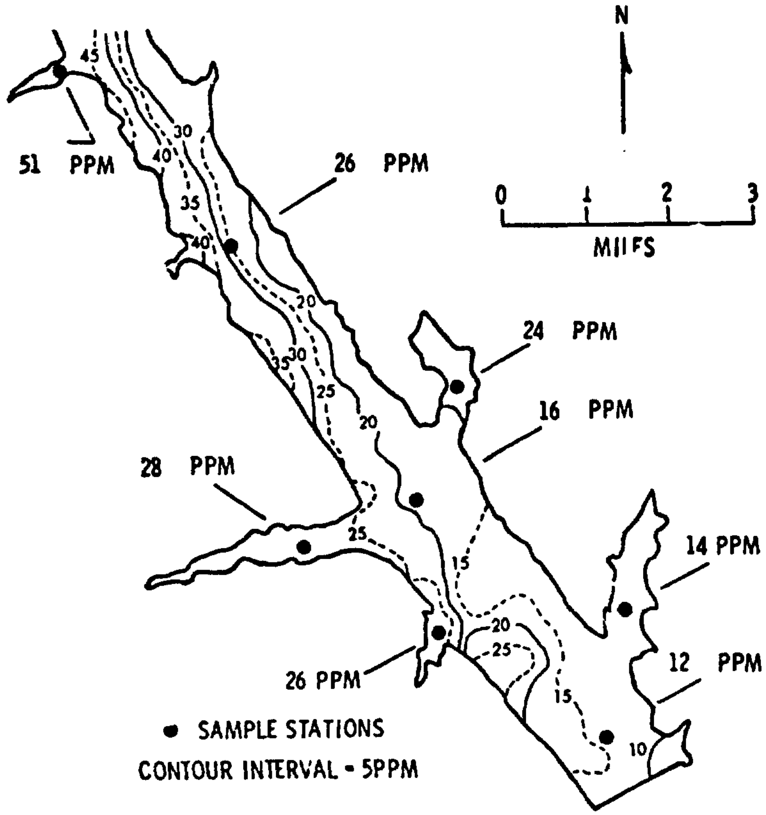


FIGURE 11. SUSPENDED SOLIDS CONTOUR MAP OF TUTTLE CREEK RESERVOIR (AUGUST 14, 1972 ERTS-1 ID NO. 1022-16391-5) DERIVED FROM CCTS (MSS 5) FOR 4 LANDSAT-1 PASSES.

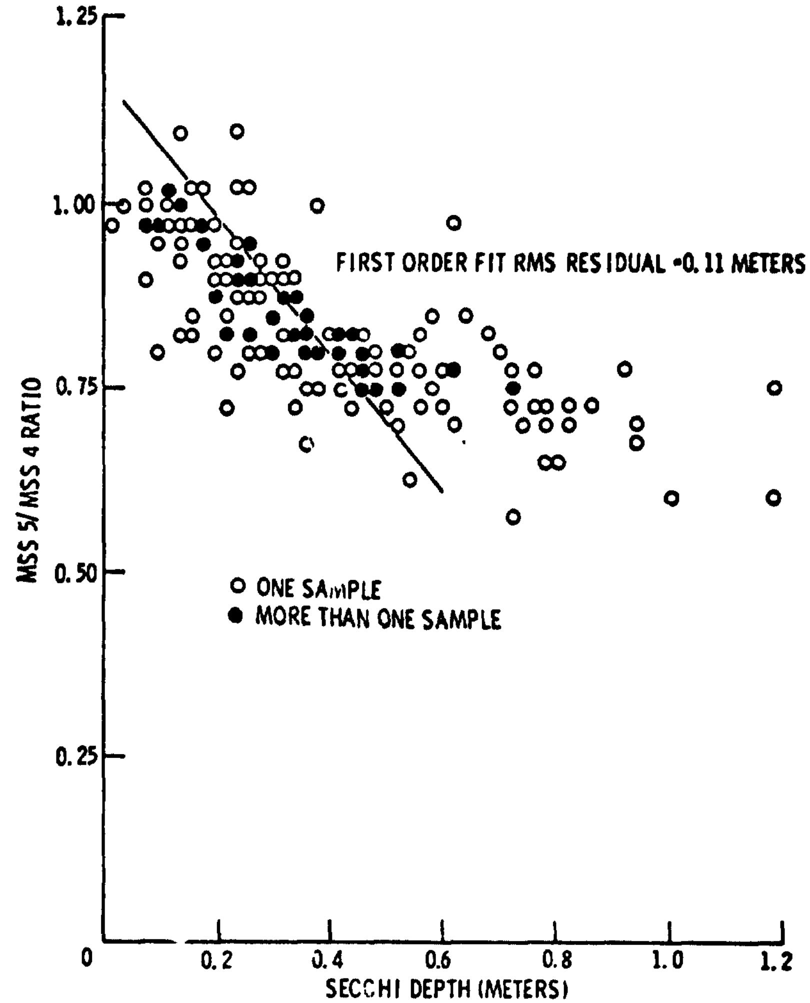


FIGURE 12. MSS 5/ MSS 4 CCT RATIO VS. SECCHI DEPTH FOR 171 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT LANDSAT-1 CYCLES.

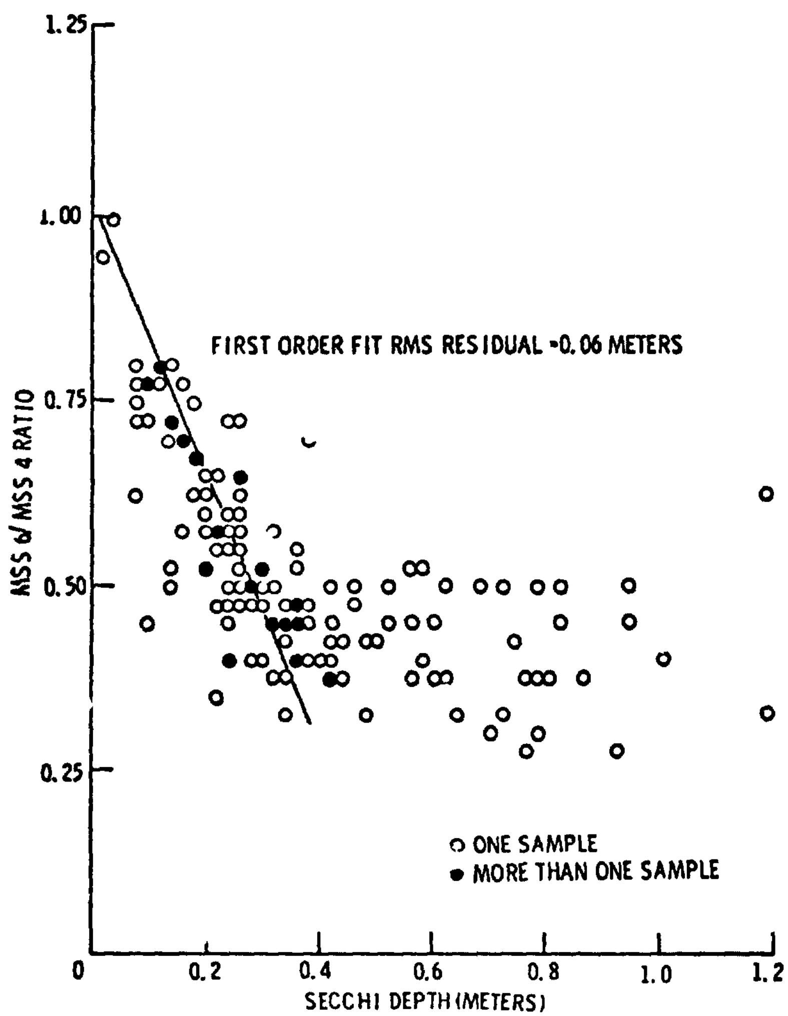


FIGURE 13. MSS 6/MSS 4 CCT RATIO VS. SECCHI DEPTH FOR 170 WATER SAMPLES TAKEN FROM 3 KANSAS RESERVOIRS DURING 13 DIFFERENT LANDSAT-1 CYCLES.

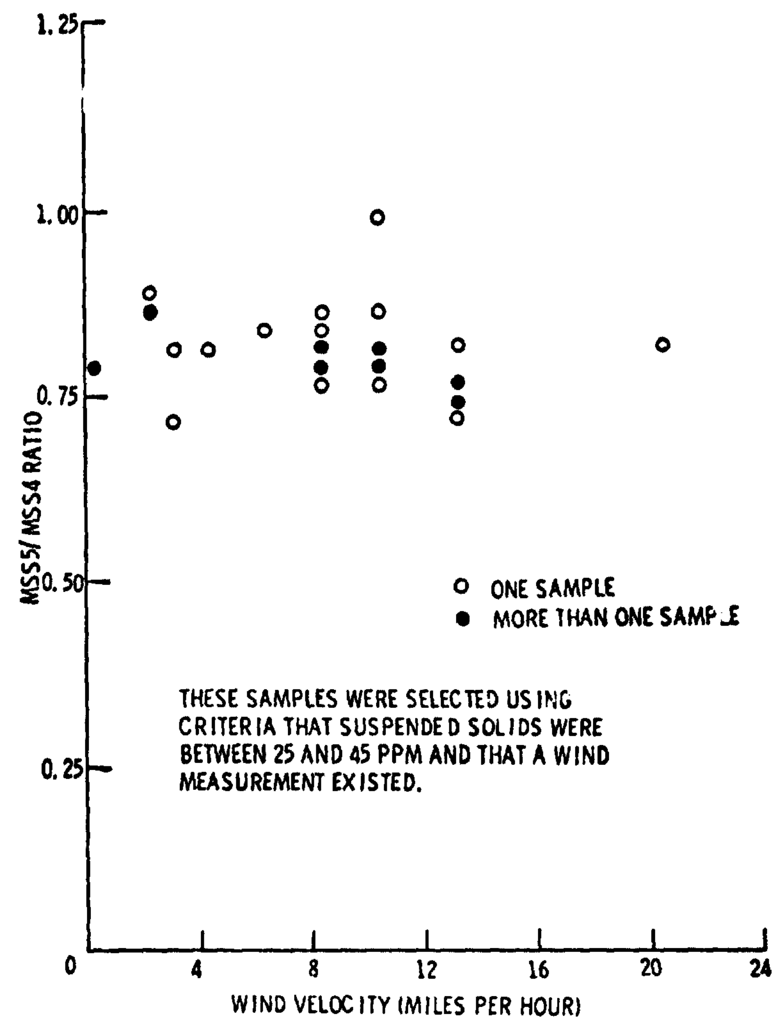


FIGURE 14. MSS 5/MSS 4 CCT RATIO VS. WIND VELOCITY FOR 35 SAMPLES TAKEN FROM 2 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD.

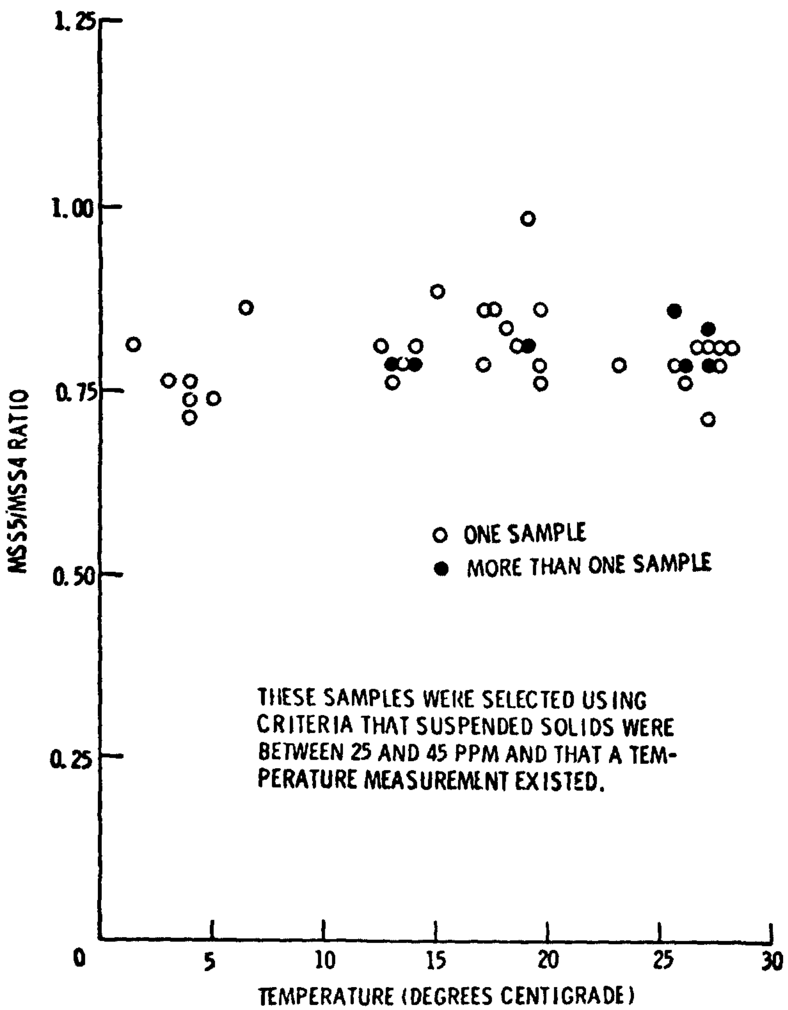


FIGURE 15. MSS 5/MSS 4 CCT RATIO VS. TEMPERATURE FOR 44 SAMPLES TAKEN FROM 2 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD.

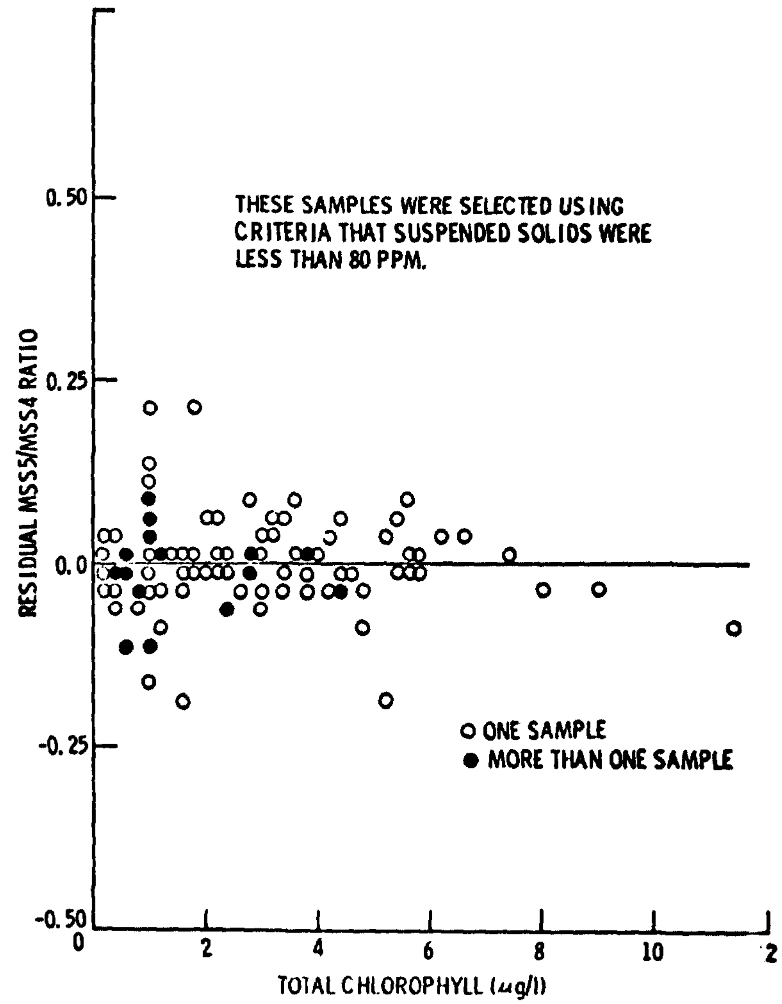


FIGURE 16. RESIDUAL MSS 5/MSS 4 CCT RATIO VS. TOTAL CHLOROPHYLL FOR 106 SAMPLES TAKEN FROM 2 KANSAS RESERVOIRS OVER A 13 MONTH PERIOD. RESIDUAL WAS OBTAINED BY SUBTRACTING LINEAR DEPENDENCE ON SUSPENDED SOLIDS.

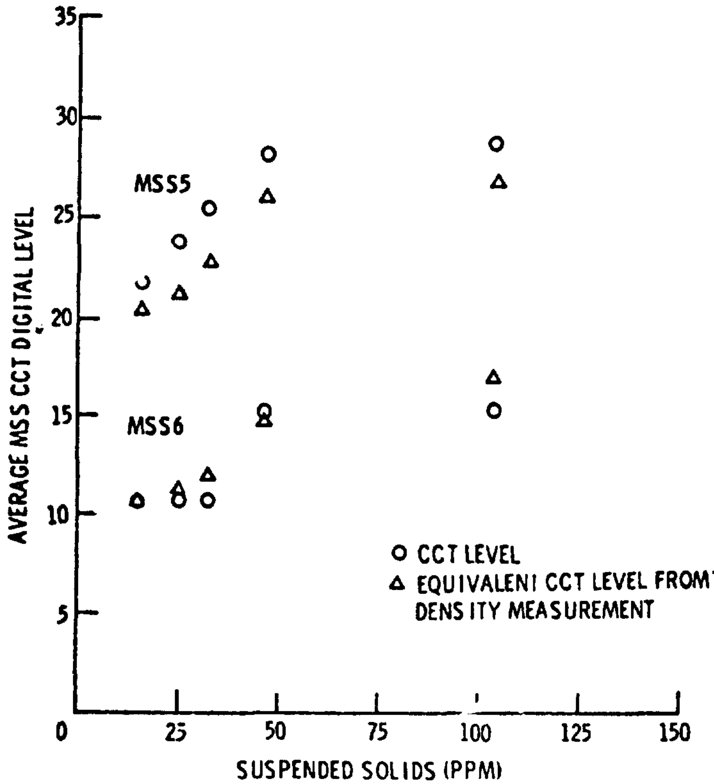


FIGURE 17. COMPARISON OF CCT DIGITAL LEVELS WITH IMAGE DENSITY MEASUREMENTS FOR TUTTLE CREEK RESERVIIR, LANDSAT CYCLE 4. DENSITY MEASUREMENTS WERE CONVERTED TO EQUIVALENT CCT LEVELS BY USING STEP WEDGE AT BOTTOM OF IMAGE.

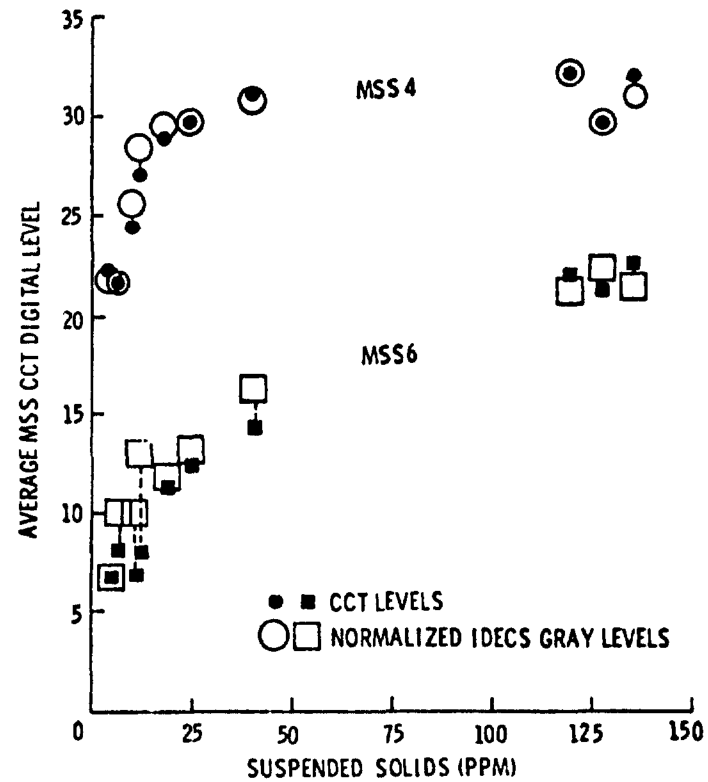


FIGURE 18. COMPARISON OF CCT LEVELS WITH IDECS LEVELS FOR PERRY, LANDSAT CYCLE 2.

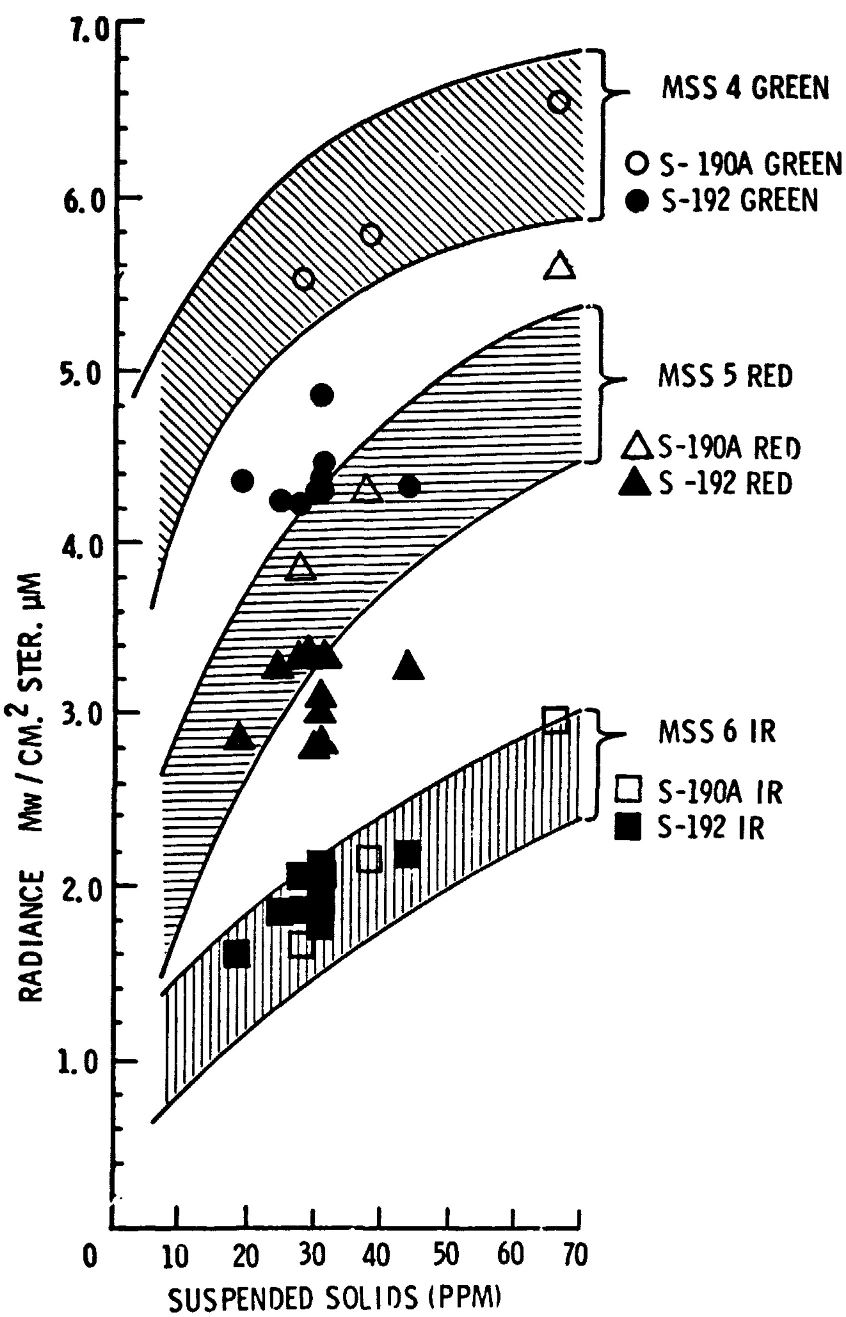


FIGURE 19. RADIANCE VS. SUSPENDED SOLIDS. ONE SL-3 PASS (SUN ANGLE = 44°) OVER 3 S.E. KANSAS RESERVOIRS AND 7 LANDSAT PASSES (SUN ANGLE = 40°- 54°) OVER 3 N.E. KANSAS RESERVOIRS.

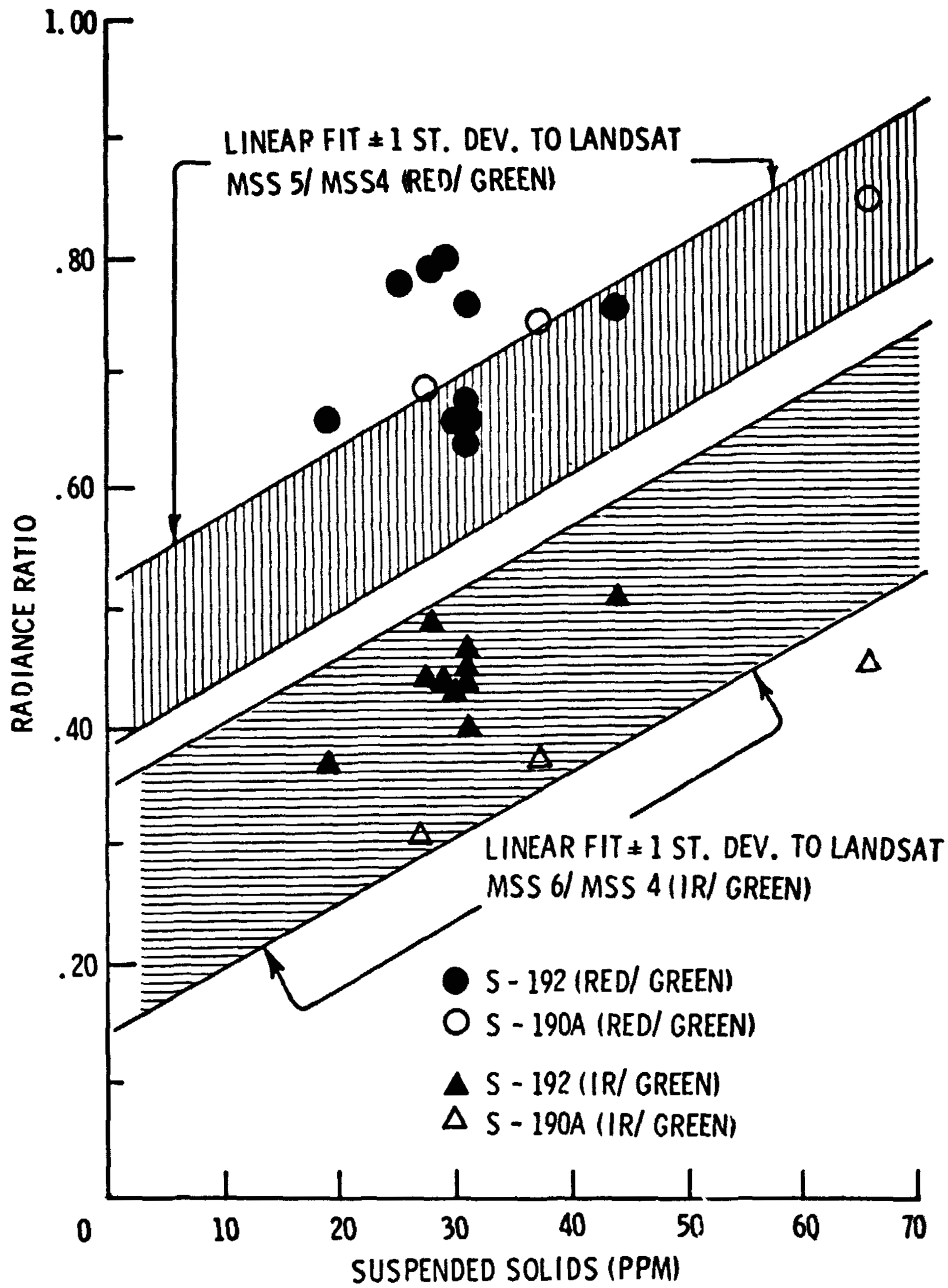


FIGURE 20.RADIANCE RATIOS VS. SUSPENDED SOLIDS. ONE SL-3 PASS((9/18/73) OVER 1 S.E. KANSAS RESERVOIR AND 13 LANDSAT CYCLES OVER 3 RESERVOIRS IN N.E. KANSAS OVER THE PERIOD JULY 25, 1972 TO AUG. 27, 1973.

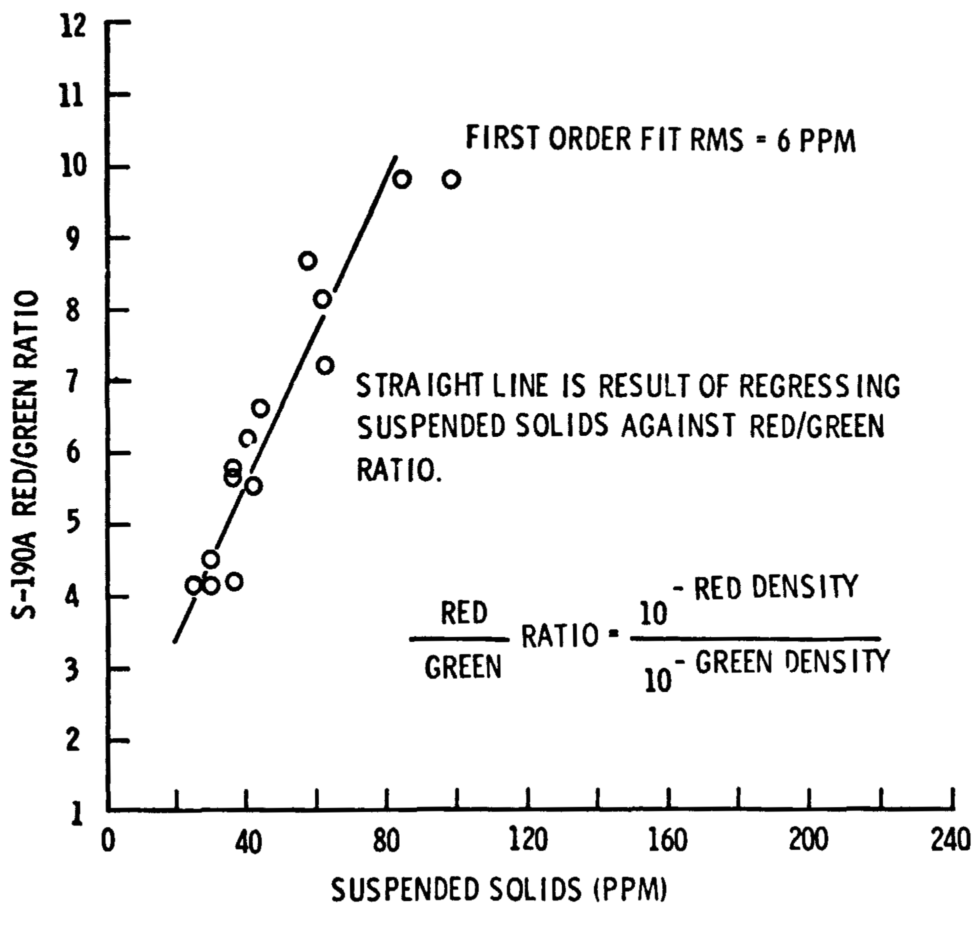


FIGURE 21. RED/ GREEN RATIO VS. SUSPENDED SOLIDS FOR WATER SAMPLES TAKEN FROM 3 S.E. KANSAS RESERVOIRS, SEPT. 18 1973.

LANDSAT-1 DATA AS IT HAS BEEN APPLIED FOR LAND USE AND WATER QUALITY DATA BY THE VIRGINIA STATE WATER CONTROL BOARD

E-10

I. - THE STATE PROJECT

By Peter L. Trexler
Assistant Director
Division of Surveillance and Field Studies
Virginia State Water Control Board

N76-17494

ABSTRACT

In March, 1974, the Virginia State Water Control Board embarked on a program with the National Aeronautics and Space Administration (NASA) User Demonstration Group, LANDSAT Resources Branch of the Applications Directorate. The program first centered on a proposed development approximately ten miles west of Richmond, Virginia, which involved land use monitoring as well as water quality monitoring of the Swift Creek Reservoir and the Brandermill development which was to be built around the Reservoir. After several months of both water quality and LANDSAT-1 monitoring, it was decided that the water was high quality and homogenous throughout the Reservoir. At this time a decision was made to continue Reservoir monitoring on days of LANDSAT-1 passovers and also to monitor another nearby reservoir, Lake Chesdin, which was of generally poorer water quality and not homogenous. Concentration on land use, however, was to remain in the Swift Creek Reservoir area. After only nine months of work with LANDSAT-1 imagery, we have found data to be very helpful in both water quality monitoring and land use monitoring.

Water quality monitoring in Swift Creek and Lake Chesdin Reservoirs by LANDSAT-1 has proved useful in the following ways:

1. It has helped determine valid reservoir sampling stations.

2. It monitors areas of the Reservoirs which are not accessible by land or water.

3. It gives the State a viable means of measuring Secchi depth readings in these unaccessible areas.

4. It gives an overview of trends in changing sedimentation loadings during a specific period of time and will class these waters into various categories.

5. It enables the State to inventory all major lakes and reservoirs and gives accurate acreage estimations of lakes and reservoirs in each region.

Land use monitoring by LANDSAT-1 in the area around the Swift Creek Reservoir has been extremely useful in the following ways:

1. It has been found that LANDSAT-1 is exceedingly accurate in monitoring land use changes in any specific area (Example: Swift Creek Reservoir-Brandermill area).

2. LANDSAT-1 monitoring can evaluate possible long-term environmental effects of the Brandermill development on the Reservoir as applied to completing environmental impact statements.

3. LANDSAT-1 data will aid in monitoring and predicting population shifts which will key future water quality problems.

Problems which exist for the present and the future with organizations such as ours using available LANDSAT-1 or LANDSAT-2 are as follows:

1. Because of 18-day lapses between passovers and the limitation of cloud cover at passover times, areas cannot be monitored with any type of consistency.

2. NASA, by design, is not user oriented, therefore, any sort of permanent user program must either be taken on by the agency or contracted with a company such as Bendix or General Electric. In each case, considerable expense would be involved thereby making such a program unfeasible for small state agencies.

3. LANDSAT-1 and -2 are both devoid of sensors which would prove to be very valuable in the work in which this agency is involved, the most notable being a thermo sensor.

In conclusion, the State Water Control Board has found LANDSAT-1 imagery to be valuable in both land use and water quality monitoring. This agency also feels there is great potential in satellite monitoring for the future as the science comes of age and various sensors are added to future vehicles. We do feel that cost is probably the major problem with the program at this time, but solutions are not impossible and will be forthcoming.

INTRODUCTION

In February of 1974 personnel from the Virginia State Water Control Board (VSWCB) office were attracted by an article in a magazine that dealt briefly with the potential of LANDSAT satellite monitoring as applied to water quality studies and land use. After writing the National Aeronautics and Space Administration (NASA) at the Goddard Space Flight Center, Greenbelt, Maryland, it was learned that we could visit the complex to learn more about the potential use of LANDSAT. In March, 1974, a visit was made by me and two other members of the VSWCB staff. We were very impressed with satellite monitoring system and felt that it held great potential for our organization; this we related to NASA personnel.

In January, 1974, the VSWCB began a water quality study on the Swift Creek Reservoir, a 1700 acre impoundment, which supplies drinking water to some 30,000 people. The reason for such a study was a proposed development to be built around the Reservoir by Sea Pines, Inc. The development was to be called Brandermill, Inc. It would encompass approximately 3,000 acres, take five years to complete, and house some 70,000 people (Reference: Figure A). The VSWCB felt that reservoir monitoring would serve two purposes:

1. It would be an opportunity to monitor the water quality during the five year period of construction to ensure that it would not suffer due to this development.

2. It gave the VSWCB an opportunity to work directly with a private firm (Sea Pines, Inc.) to further ensure non-degradation of the water quality in the Reservoir.

After further discussion of LANDSAT use with NASA personnel, it was decided that the Swift Creek Reservoir held potential as a study area for LANDSAT monitoring. The Reservoir was large enough to be monitored accurately, and the greatest problem we anticipated with the construction, namely siltation runoff, could be measured by satellite reflectance. It was at this time that Dr. John Barker of the NASA Earth Resources Branch at Goddard Space Flight Center contacted my office.

After several months of both VSWCB and LANDSAT-1 monitoring, it was decided by the two groups involved that Swift Creek Reservoir was homogenous throughout and water quality variation would have to be found in another body of water, preferably within the same satellite image. After some field examination, it was decided that Lake Chesdin, a 3,060 acre lake south of Swift Creek Reservoir, would be chosen. This decision was made on the basis of a preliminary investigation that indicated serious siltation problems on the Lake. Lake Chesdin supplies drinking water for areas in Chesterfield County, Virginia.

NOMENCLATURE

Secchi disk. - Black and white circular disk which is lowered into the water until it just disappears from view. The distance between the disk and the surface of the water is the Secchi reading in inches.

Turbidity meter. - An instrument which is used to measure the transmittance of light through that water as measured in Jackson Turbidity Units (JTU).

Total solids. - Total solids is defined as the sum total of the dissolved solids (those solids which are in true solution) and total suspended solids (includes settleable solids). Consists of both organic and inorganic solids and is expressed in mg/l.

Total volatile solids. - That portion of total solids which can be ignited at a constant temperature of 600°C thereby classing such material as organic. Expressed in mg/l.

Total fixed solids. - That portion of total solids which will not oxidize at 600°C thereby classing such materials as inorganic. Expressed in mg/l.

Total suspended solids. - The total amount of residue which is filterable with a Reeve Angel grade 934AH fiberglass filter. Consists of both organic and inorganic material. Expressed in mg/l.

Volatile suspended solids. - That portion of total suspended residue which can be ignited at 550°C thereby classing such material as organic. Expressed in mg/l.

Fixed suspended solids. - That portion of the total suspended residue which will not oxidixe at 550°C thereby classing such material as inorganic. Expressed in mg/l.

Tri-depth sampling. - Method of sampling by which three samples are taken from each point or station. These samples are taken at surface, 60% from surface, and 95% from surface of water.

Mid-depth sampling. - Method of sampling by which a single sample is taken from each point or station at 60% from water surface.

Stratification. - Vertical temperature layers in water usually associated with deep lakes and reservoirs.

APPROACH

Sampling began on the Reservoir in January, 1974. Originally, there were five sampling stations around the main Reservoir body (Reference: Figure B). These stations were sampled monthly at tri-depth for the first two months. Upon review of the satellite imagery and ground observation, it was decided that the impoundment was shallow enough (average depth nine feet) so that stratification was not occurring; therefore, mid-depth sampling replaced the tri-depth sampling.

In April, 1974, when NASA began to work with the VSWCB, it was recognized that an increase in sampling stations would be beneficial. None of the original stations were deleted and five new stations were added (Reference: Figure C). Also, at this time Secchi disk readings were initiated at each station as well as lab and field turbidity readings. Other parameters to be examined were total solids, volatile and fixed, and suspended solids, volatile and fixed. All of these parameters were to be used to relate to reflectance of LANDSAT imagery. Sampling runs were to coincide directly with the time of satellite overpass schedules. Construction at Brandermill began in the later part of June, 1974.

Certain difficulties occurred during the nine months of sampling on overpass days. These involved equipment and procedural malfunctions, weather conditions, and in two cases an incorrect overpass schedule. As with all new programs in which new sampling techniques are involved, members of the VSWCB staff incurred certain problems with the equipment and with the procedure used in handling this equipment. When there were no field problems, cloud cover interfered; and when neither of these occurred, it was discovered that in October and November of 1974 the overpass schedule was in error. In summary, out of the nine months of sampling and overpass days only two months of images were analyzed, June 15 and September 13.

During the summer and early fall, NASA and the VSWCB worked closely to coordinate efforts including visits to Richmond and Goddard Space Flight Center. During the trips to Swift Creek and Lake Chesdin Reservoir, photographs were taken for ground truth purposes. On the September visit Secchi depth readings were taken during satellite overpass. Large variations were found throughout the Lake, especially in one area which was protected by a causeway and a bridge. Here Secchi readings were twice as great as in other parts of the Lake. Other VSWCB field personnel were simultaneously sampling on Swift Creek Reservoir. Cloud cover was at a minimum and all equipment functioned properly.

From this data and the June data, Dr. Barker and I were able to gather a great deal of information relating to the project. By comparing the differences in the June and September images, the Brandermill construction area was pinpointed and its acreage measured. Airplane flights were made by VSWCB personnel to produce photographs for this land use classification.

Visits to NASA, Goddard Space Flight Center, included working sessions on both the General Electric Image 100 and the IDAMS computer systems. These sessions proved beneficial; NASA personnel obtained information on ground truth and VSWCB personnel became more familiar with the classification techniques involved in digital image processing. Seeing the projects produced was essential in supplying the appropriate ground observations.

CONCLUSION

With field work completed, the VSWCB began to receive from NASA satellite imagery and plots which demonstrated a considerable amount of usefulness in our assessment of the entire program. Water quality monitoring on Swift Creek Reservoir and Lake Chesdin by LANDSAT-1 was demonstrated useful in the following ways:

1. Sampling and Overview. - Instead of a hit-and-miss system of determining sampling stations, satellite classification products have guided our personnel in choosing stations that are more representative of the total picture. Two areas on Lake Chesdin show much higher quality of water than the main body, Namozine Creek and Whipponock Creek (Reference: Figure D). On Swift Creek Reservoir water does appear homogenous, yet, any future problems that may occur will be noted much earlier because of the rearrangement of sampling stations due to LANDSAT. Imagery gives an overview of trends in changing sedimentation loadings during a specific period of time and then these waters may be arranged into various categories of loadings.

2. Inaccessible Areas. - Imagery can be useful in monitoring areas not accessible by land or boat or at least not easily accessible by land or boat. Examples of this are seen in the Goose Island portion of Lake Chesdin (Reference: Figure D) and the upper reaches around station #5 on Swift Creek Reservoir (Reference: Figure C). With satellite monitoring of these stations, the VSWCB can save 40 man-hours per year and laboratory cost in sampling programs; and annual or semiannual review should reveal problems which may occur in the inaccessible areas.

3. Reduced Manpower and Increased Coverage. - A regular program of water quality monitoring via satellite should reduce manpower requirements and substantially extend the coverage of the state lake monitoring programs as they pertain to siltation problems. If a problem area is discovered by imagery, action can be initiated thereby eliminating useless trips.

4. Acreage. - LANDSAT imagery enables the State to inventory major lakes and reservoirs and establish accurate acreage estimations of these lakes and reservoirs. This phase of monitoring is not only important in that it can measure acreage sizes, which can be done as accurately by other methods: its importance lies in the potential of measuring changes in acreage. By normal methods, acreage changes in lakes and reservoirs are only measured every ten years by the United States Geological Survey (USGS). Satellite imagery can update changes as needed. Although this phase of the program has not gone beyond two major lakes in the Richmond area, it is certainly safe to assume that it holds potential throughout the State of Virginia.

5. Watershed Land Use. - In addition to measuring the size accurately for each major lake or reservoir, NASA has demonstrated that

watershed boundries can be plotted thereby giving users such as the VSWCB an overall view of each watershed. With this knowledge, agencies will be able to assess water quality problems as they pertain to land use in the watershed. If any type of accurate assessments are to be made in the future, information of this type will be necessary.

Each of these five major categories from LANDSAT-1 form a picture of the two lakes studied that has not been surpassed by any other method of evaluating siltation problems.

Changes in use directly impact water quality studies. If a population shift is experienced in any specific area, it can be anticipated that several things will happen to the water quality in that area. Unless the people involved in the actual construction are careful to limit to a minimum any disruption of underbrush and trees, it is certain that there will be siltation runoff from cleared areas. After construction is over and the area established, the presence of populace will contribute to further degradation of water quality. Complications such as the above serve to point out the value of land use monitoring via satellite.

LANDSAT-1 land use monitoring in the area around Swift Creek Reservoir proved helpful in monitoring land use changes. Using two images, one on June 15, 1974, (before actual construction had begun) and the other September 13, 1974, (after the major part of clearing had been completed) NASA personnel were able to plot construction areas to such a fine degree as to pinpoint small waterholes on the fairways of the golf course. With this type of accuracy, the VSWCB can get an overall view of any existing or potential problems as they pertain to the construction project. Current spatial resolution appears adequate for monitoring change in land use. It is reasonable to assume that a man preparing an environmental impact statement can use LANDSAT data to evaluate land use and its effects on watersheds as was done by our office with the Brandermill project.

The VSWCB can foresee other State agencies using the same data that we receive and applying it in various ways, such as forestry classification, population studies, and many others. An effort has been made to expand interest for LANDSAT use among other State agencies. Contacts have been made and response has generally been positive. As new awareness generates response, we at the VSWCB foresee an increase in use within the State government.

As with all projects of this type, problems were encountered. It should be understood that some of the difficulties listed below are inherent as a part of the nature of environmental satellite monitoring; however, many of these difficulties can be corrected or improved with future satellites and with a broadening of techniques and increase in use.

1. Frequency of Coverage. - Because of 18-day lapses between LANDSAT 1 overpasses and cloud cover in this region, areas cannot be monitored more frequently than once every two months. Consequently, the monitoring of water quality cannot be used as an instantaneous means of alert.

2. Cost. - The next and most significant problem a state agency faces is funding. NASA by design is not user oriented; therefore, anyone who finds the type of monitoring in which we have been involved to be of use must approach a private concern for a contractional agreement. This service appears to be too expensive. There are several solutions to this situation, the most notable in my opinion being the federal government's reevaluation of NASA to become user oriented. If this were a federal government

program, states would only have to share a small percentage of the cost. I can see many advantages to this including:

a. NASA would receive additional funding to increase staff to support the program.

b. The program would be available to many agencies, such as ours, that are already aware of LANDSAT potential and also to untold numbers of agencies who are not aware of LANDSAT potential.

c. With increased use, the program should become more cost effective and usable in various applications.

d. Lastly, such a growth would serve to benefit the environment. With increased use, advancements in technology and new environmentally designed satellites, we could not help but receive a greater understanding of our environment, its problems, and solutions to these problems. This is the essence of the program.

3. Sensors. - The VSWCB would especially like to see additional sensors on satellites, the most notable of which would be a thermo sensor with resolution of better than one hundred meters on the side. An instrument such as this could prove invaluable to environmental work as related to thermo nuclear power plant discharges, sewage disposal diffusion patterns, air pollution problems, and many others. Certainly there are other sensors which would be of value, but it is our opinion that the thermo sensor with temperature sensitivity of at least 0.3°C should be one of the first to be considered for the future.

In summary, the VSWCB has found our program with NASA to be one of great value as applied to the Brandermill-Swift Creek Reservoir and Lake Chesdin projects. We have gained a great deal of knowledge about these particular impoundments and an acute insight into the nature of the problems.

ACKNOWLEDGEMENTS

The writer wishes to thank the following agencies and individuals who have participated in this program.

Dr. John Barker, User Demonstration Group, Goddard Space Flight Center, Greenbelt, Maryland
Brandermill, Inc. (Division of Sea Pines, Inc.)
Chesterfield County Water Treatment Plant personnel and engineering staff
John J. Cibulka, Director, Piedmont Regional Office, Virginia State Water Control Board
Eugene T. Jensen, Executive Secretary, Virginia State Water Control Board
Ms. Donna Lietzke, Secretary, Division of Surveillance and Field Studies, Piedmont Regional Office, Virginia State Water Control Board
A. H. Paessler, Deputy Executive Secretary - Operations, Virginia State Water Control Board
Mrs. Dorthy Schultz, General Electric Company, Greenbelt, Maryland
Clark M. Thaler, Director, Division of Surveillance and Field Studies, Piedmont Regional Office, Virginia State Water Control Board
Virginia Commission of Game and Inland Fisheries
Virginia State Water Control Board, Piedmont Regional Office, Division of Applied Technology
Virginia State Water Control Board, Piedmont Regional Office, Division of Surveillance and Field Studies

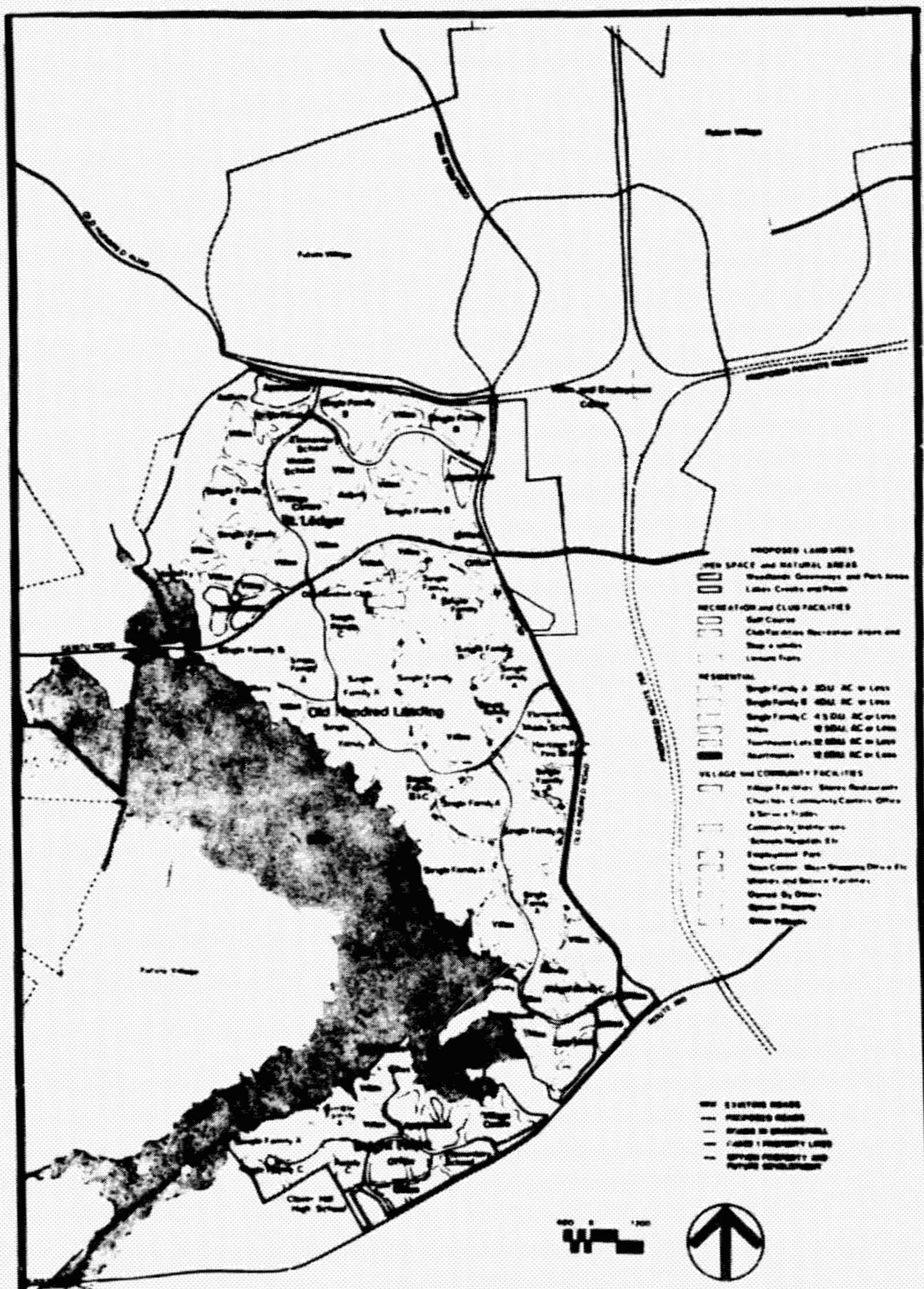
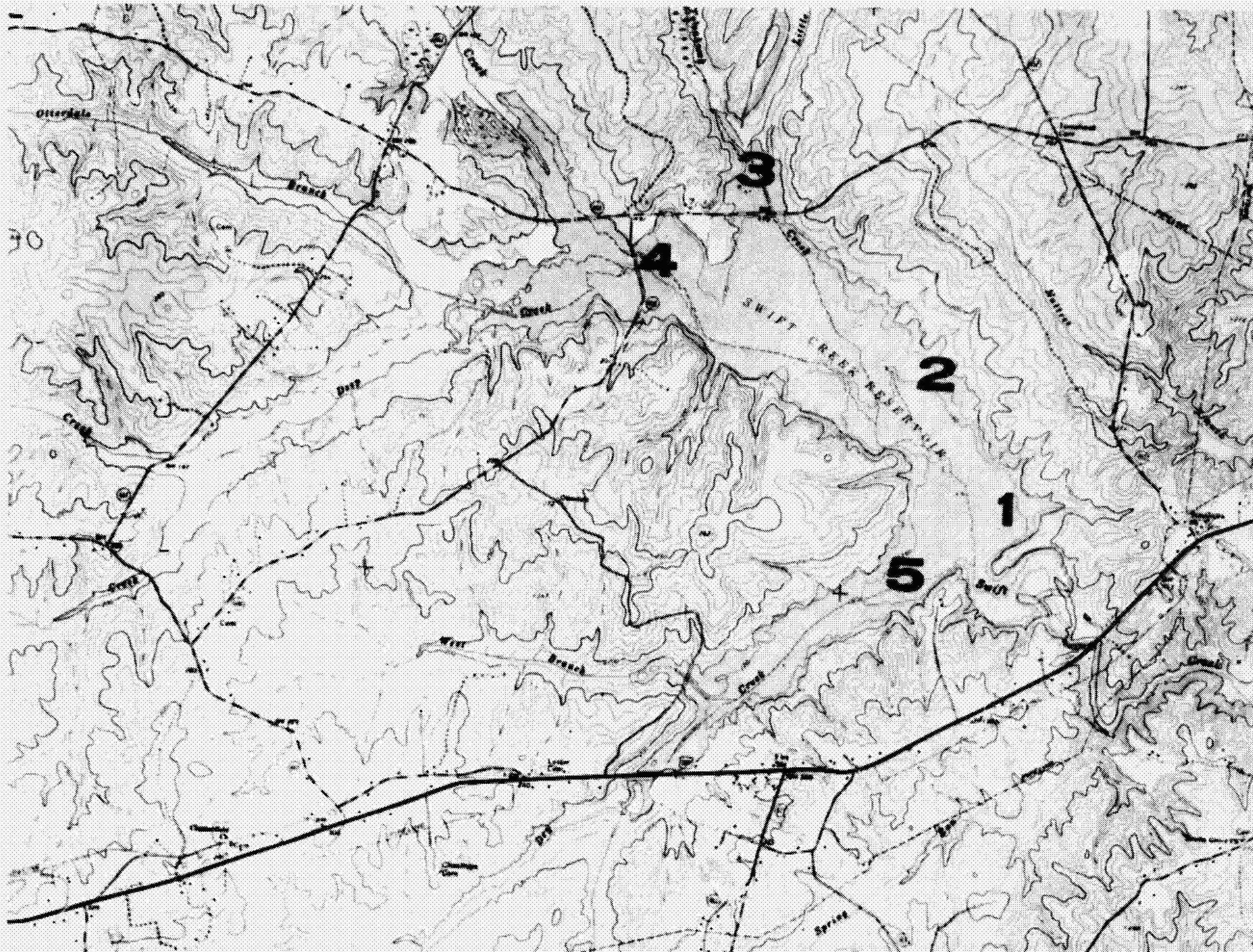


Figure A



SWIFT CREEK RESERVOIR
1
2
3
4
5
Otterdale
Branch
Creek
Deep
West Branch
Swift
Spring

Figure B

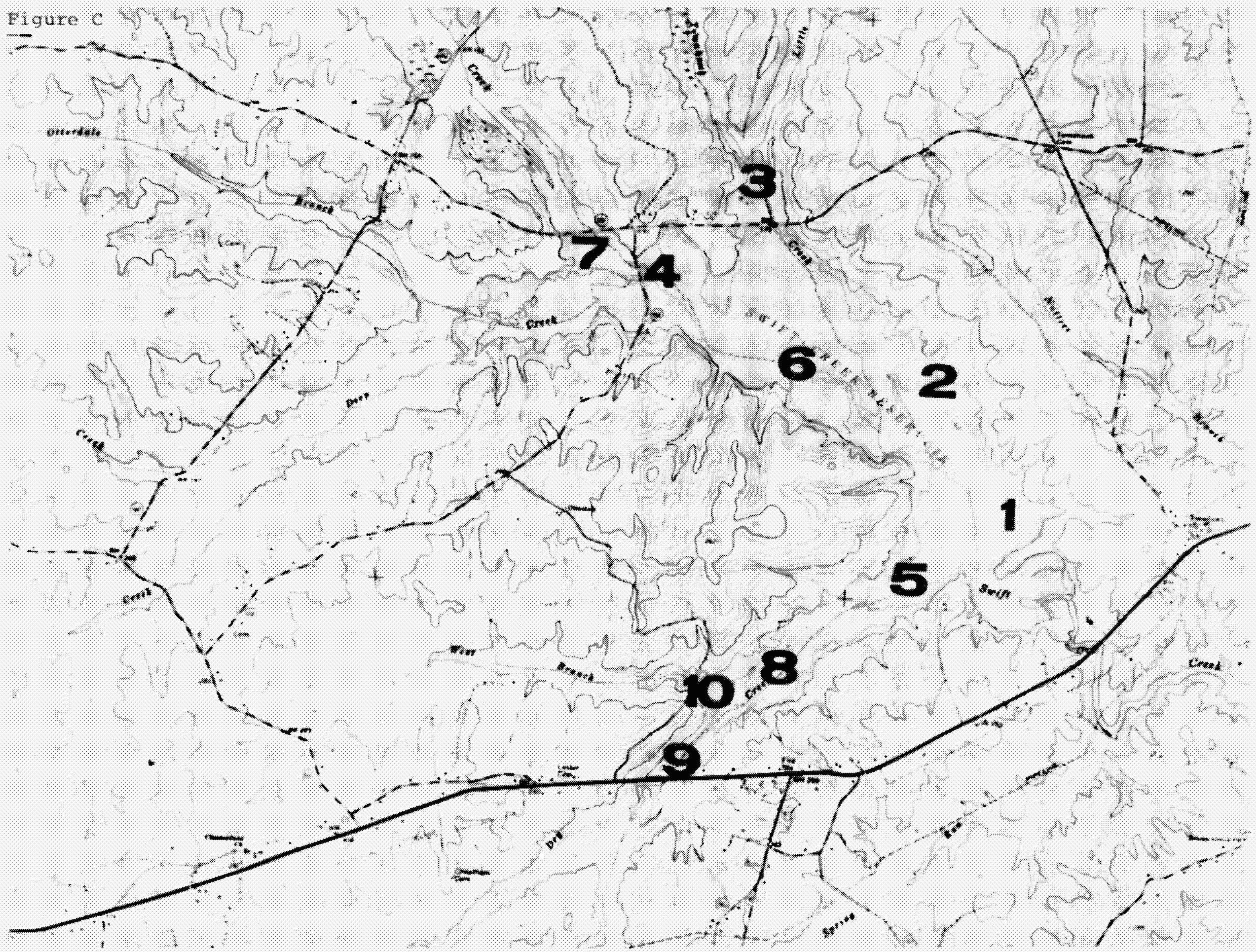


Figure C
1
2
3
4
5
6
7
8
9
10
Otterdale
Branch
Creek
Swift
West
Branch

Figure C

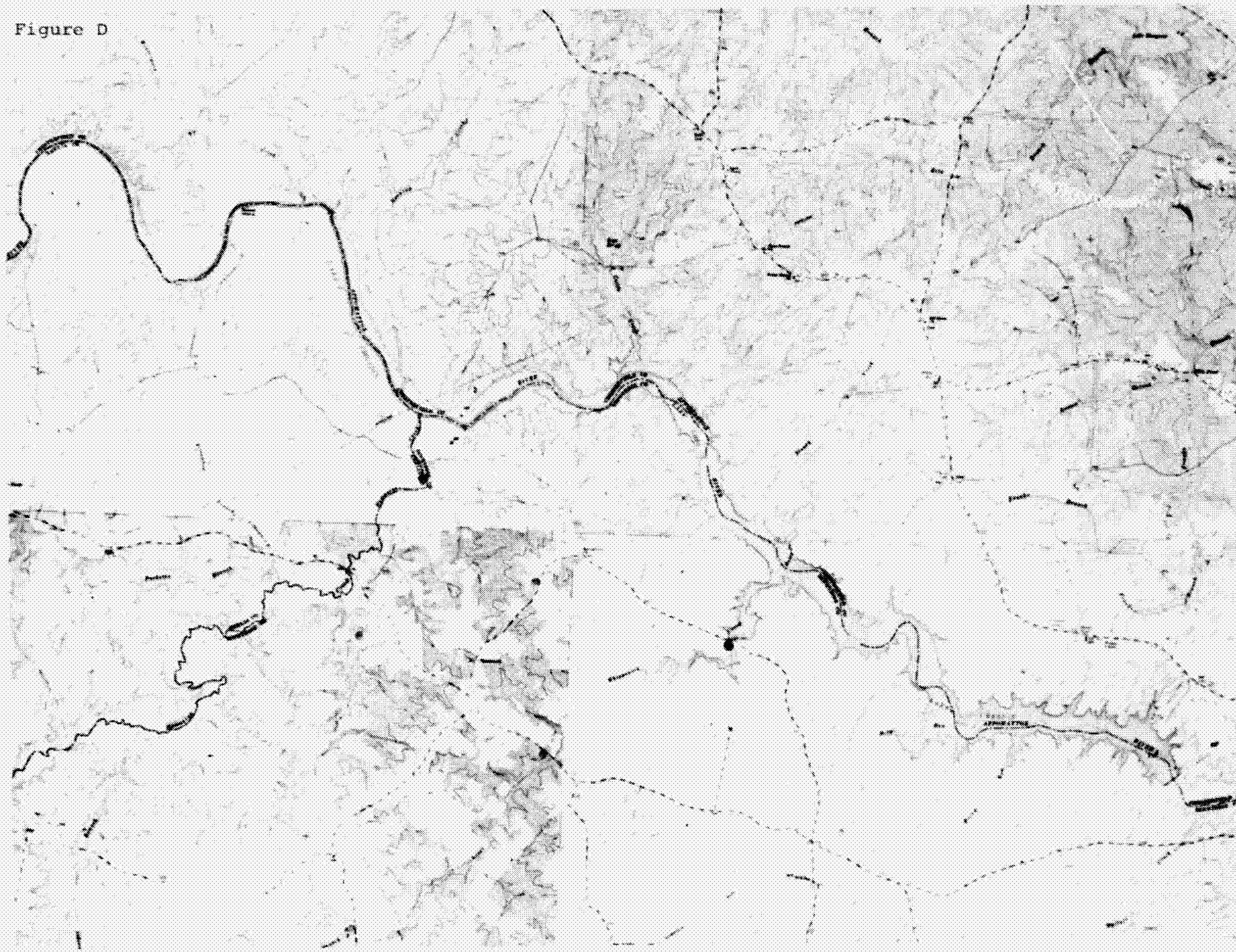


Figure D

II.- MONITORING WATER QUALITY FROM LANDSAT

By John L. Barker, Earth Resources Branch, NASA/GSFC, Greenbelt, Maryland

ABSTRACT

Water quality monitoring possibilities from LANDSAT were demonstrated both for direct readings of reflectances from the water and indirect monitoring of changes in use of land surrounding Swift Creek Reservoir in a joint project with the Virginia State Water Control Board and NASA. Film products were shown to have insufficient resolution and all work was done by digitally processing computer compatible tapes.

It was shown that areas of individual water bodies could be measured from LANDSAT with an accuracy that decreased from ±1% at 500 hectares to ±8% at 5 hectares. Mixed land and water pixels with more than 30% water were identified from low MSS-7 reflectance values. Since measurements of large bodies have relatively small errors, since random errors in the calculation of the area of small bodies will cancel out when several single body areas are summed, and since there were no observable systematic errors, it seems that water inventory maps from LANDSAT within a particular region can be accurate to ±1% in identifying the total area of water. Although mixed pixel methods were more accurate than pure 100% water pixel methods, for some applications pure pixel methods might be adequate for areas above 20 hectares as long as a theoretical correction for border pixels is made. For guaranteed repeat monitoring from LANDSAT, the homogenous body of water must be at least 160m by 160m or 2.5 hectares (6.2 acres) in size.

LANDSAT reflectances from water in the visible (MSS-4 and MSS-5) and near-infrared (MSS-6) spectral bands were shown to be nearly perfectly correlated and spatially coherent for both Swift Creek Reservoir and Lake Chesdin Reservoir, which has a ten times greater flow rate due to input from the Appomatox River. Maps of different reflectances in water were derived using only MSS-5 values for these two reservoirs. Secchi depth and MSS-5 reflectance values showed a 98% inverse correlation on one date in Lake Chesdin Reservoir which may be due to the mutual dependence on total solids content. It is expected that calibration equations of LANDSAT reflectance and a water quality parameter will be necessary for each region which supplies different types of organic and inorganic particles. For Lake Chesdin Reservoir it was possible to distinguish classes of water from LANDSAT imagery which differed by about 5cm at the most sediment-laden and reflective Secchi depths. Direct monitoring of water quality seems to be most useful for observing changes in water patterns and devising and verifying water sampling programs.

Perhaps the greatest potential contribution of LANDSAT is through indirect interpretation, by detecting changes in land cover in a watershed. Land cover maps of the 18,000 hectare Swift Creek Reservoir watershed were prepared for two dates in 1974. A significant decrease in the pine cover was observed in a 740 hectare construction site within the watershed. A measure of the accuracy of classification was obtained by comparing the LANDSAT results with visual classification at five sites on a U-2 photograph. Such changes in land cover can alert personnel to watch for potential changes in water quality.

INTRODUCTION

The Virginia State Water Control Board (VSWCB) has the responsibility for monitoring the water quality of all bodies of water in Virginia. The primary objective of this paper is to identify ways in which remotely sensed satellite data might help support this program, both qualitatively and quantitatively. Working with VSWCB, various products from image processing of LANDSAT data were prepared for evaluation by NASA/VSWCB personnel, as well as other potential users.

An object of immediate concern to VSWCB was the possible change in water quality due to the construction of a 1000 hectare (2500 acre)[1] residential community called Brandermill on land immediately adjacent to 600 hectare Swift Creek Reservoir (SCR). Therefore, the possibilities of using data from the Earth Resources Technology Satellite [2] to monitor environmental impact on this water body were investigated both directly through readings of reflectances from the water, and indirectly by monitoring changes in reflectances from the land surrounding the reservoir.

For purposes of discussion, the evaluation has been divided into four sections:

- Spatial and spectral resolution of LANDSAT film products as compared to digital LANDSAT data from Computer Compatible Tapes (CCT).
- A determination of the precision and accuracy of measureing surface areas of bodies of water from LANDSAT.
- LANDSAT monitoring of Secchi depths and total solids in Lake Chesdin Reservoir (LCR), and choice of water sampling sites at both LCR and SCR based on the synoptic overview of reflectances from LANDSAT.

[1]One hectare is 0.01 Km^2 and equals 2.5 acres.

[2]"ERTS" has been renamed LANDSAT.

- LANDSAT monitoring of changes in land cover in the SCR watershed, in the Brandermill construction site, and in the area of overlap between the construction site and the watershed.

DIGITAL VERSUS FILM PRODUCTS

Digital data are necessary for most water quality monitoring. This can be illustrated by comparing a standard black and white print of a LANDSAT image (Figure 1), and a photographic blow-up (Figure 2) from it, with a pseudo-color pixel[3] print of the same area (Figure 3) prepared from a CCT.

The photographic blow-up in Figure 2 was prepared from a standard 70mm negative of MSS band 7[4] for the LANDSAT image of 13 September 1974. It appears slightly out of focus because individual points of information can no longer be resolved at this scale. Photographic products have the inherent limitation that some information is lost in each successive generation of photographs. While some of the fuzziness of Figure 2 can theoretically be attributed to loss in printing from Figure 1, in this case the detail is not present in the original negative. Some of the information from the satellite has already been lost in the preparation of the second or third generation negatives used to prepare negatives for the user.

How does one extract the maximum amount of information from the satellite? Figure 3 is a pseudo-color pixel print prepared by computer assignment of different colors to every reflectance value in MSS-7. The choice of "pseudo-colors" is arbitrary and not necessarily optimum, but illustrates the ability to make each different reflectance value visible when one starts with the original digital data on the CCT's. Furthermore, every pixel can be seen as a distinct rectangle. One of the inherent advantages of digital image processing is that no information need be lost in computer processing.

---

[3] A pixel is a picture element. For LANDSAT, a typical pixel from the satellite corresponds to an area on the ground of about 57m by 79m, or .45 hectares (1.1 acres).

[4] LANDSAT has four bands of light reflectance recorded with its Multi-Spectral Spectrometer. MSS-4 (0.5 to .6 microns) and MSS-5 (0.6 to 0.7 microns) are in the visible. MSS-6 (.7 to .8) and MSS-7 (.8 to 1.1) are in the near infrared.

What is the ultimate LANDSAT resolution? Is it necessary to obtain this degree of precision when monitoring water quality? A theoretical estimate can be made of the smallest sized water area that can be reproducibily monitored from LANDSAT by knowing the size of a pixel and recognizing that the arbitrary starting point of the process of scanning on the satellite will result in pixel displacement from one date to another of up to plus or minus one column or one line, even after registration of the two images on top of each other. The nominal scan rate of the mirror in the satellite results in the storage of average reflectance values as individual pixels which are roughly centered in adjacent 57m by 79m areas on the ground. However, the Instanteous Field Of View (IFOV) of the telescope on the satellite is about 79m by 79m. Since this area is greater than the area from the average scan rate, every pixel contains an overlap contribution to its reflectance from the two adjacent pixels on the same line. This larger 79m by 79m IFOV pixel area is the limiting size in resolving reflectance values from the ground. Given the arbitrary starting point of the scan of each image, the homogeous water area on the ground would have to be at least twice as wide and twice as long as the IFOV to ensure that on every pass of the satellite at least one pixel contained nothing but reflectance from the homogeneous water area. Therefore, for guaranteed repeat monitoring from LANDSAT, the homogeneous area must be at least 158m by 158m or 2.5 hectares (6.2 acres) in size. In 50% of the images, a homogeneous area would be visible as a pixel containing 100% water if its dimensions were a factor of a square root of 2 less, namely 112m by 112m or 1.25 hectares (3.1 acres). If 2.5 hectare bodies of water, or bodies with lateral dimensions of down to 158m, are viewed as significant for purposes of repeatedly monitoring water quality from LANDSAT, then digital processing is required in order to retain all of the spatial resolution present in the data coming from the satellite.

In summary, all the spectral and spatial resolution is available from digital image processing of the CCT's, whereas film processing results in loss of information in both domains. Most potential applications for monitoring of water quality from LANDSAT seem to require digital image processing.

SURFACE AREA OF WATER

VSWCB needs to monitor the water quality of all bodies of water in the state. In order to accomplish this, they would like a periodically up-dated water inventory map which identifies the locations and surface areas of these water bodies. By monitoring changes in surface area and the creation of new bodies, the relatively understaffed field units within each region of the VSWCB can set up efficient and comprehensive water sampling programs.

LANDSAT's MSS band 7 is ideally suited for spectrally identifying water pixels because water absorbs so completely in the near infrared, relative to absorption by non-water areas. Since the question of identifying water by satellite was not in doubt, the objective of this phase of the demonstration project was to evaluate how precisely, and how accurately, surface areas of water could be measured. Sub-pixel spatial resolution is possible for determining water area because pixels containing as little as 30% water in them can be spectrally distinguished in MSS-7 from pixels containing less than 30% water. For measuring the area of water on any specific LANDSAT image, the spatial resolution is more than an order of magnitude better, i.e. of the order of 30% of a pixel which is about 0.2 hectare (0.4 acre).

Swift Creek Reservoir was chosen as the site for this evaluation of precision and accuracy because the water is maintained at the same level throughout the year. Furthermore, there is a steep shoreline and intense forest cover extends to the edge of the water. There is essentially no shore. Therefore, small changes in water level would result in even smaller percent changes in the total surface area. Seven sub-sectionsof the reservoir were used, ranging in size from about 500 hectares down to 5 hectares of water. They can be seen in a blow-up of a photograph from a U-2 aircraft flown at 60,000 feet (Figure 4) and in photographs taken from a light plane at an altitude of 300 feet (Figure 5).

Several methods of calculating areas were evaluated using these 7 sections, after converting pixel-by-pixel lists of MSS-7 into lists of per cent water (Figure 6). Lists of this type were prepared in 2 or 3 parts on three different images from 1974. One reason for this partitioning was because certain columns had been repeated in the original CCT's to fill out the overall image to 3240 columns; these repeated columns had to be removed to prevent overestimation of the area by as much as 15%. A second reason for partitioning was that a better estimate of the average reflectance of MSS-7 on land immediately adjacent to the water could be made by using the mean reflectances in separate parts. In each part, a "contrast stretch" program was used to convert reflectance values, R, into percent water, W, according to the formula:

$$W = 100 \left(\frac{RL-R}{RL-RW}\right) \qquad \text{(Equation 1)}$$

Where RL is the mean reflectance of the land pixels (read from a histogram of number of pixels versus reflectance of the part) and RW is the mean reflectance of the water. The methods were divided into two types: pure pixel methods and mixed pixel methods.

In the pure pixel methods, pixels containing 100% water were identified and then assumptions were made so that a correction could be added for the contribution from fractionally filled border pixels. The number of pure pixels was obtained by counting the number of "50's" in lists such as in Figure 6 (the list shows values of W/2) and then adding 1 to 3 of the next lower levels such as 47 and 44 until the distribution of number of pixels versus percent water was approximately level. This could have been done in the original contrast stretch program. Such an addition appears necessary to avoid underestimating the number of pixels containing 100% water. Since the mixed pixel method of area measurement is more accurate, only two pure pixel methods will be mentioned, referred to as area methods A1 and A2. Method A1 simply multiplies the number of pure pixels, P, by the area conversion factor, C:

$$A1 = C\ P \qquad \text{(Equation 2)}$$

Pure pixel area method A1 will always underestimate the area because no correction is made for border pixels. Pure pixel method A2 makes a theoretical estimate of the number of border pixels by assuming that since the area is proportional to P, then the perimeter of border pixels is proportional to the square root of P:

$$A2 = C\ (P + S\sqrt{P}) \qquad \text{(Equation 3)}$$

where S is a function of the shape of the body and can be shown to have a value between 2 (for a square[5]) and infinity for a sufficiently long and thin body of water. For sections of SCR, a value of 4 was used to show that method A2 can give an answer almost as good as the mixed pixel method until the area becomes so small that the number of border pixels, $S\sqrt{P}$, is approximately equal to the number of pure pixels, P.

In the mixed pixel methods, pixels containing some water and some land are empirically identified and their fraction of water estimated from their reflectance values, these fractions are added to the pure pixels. Only one of the many possible mixed pixel methods will be examined, the one which estimates the number of border pixels that contain at least 50% water. This area method, A3, is obtained by counting all border pixels in Figure 6 which have a value of W equal to or greater than 50, to be called border-50% pixels or B50, and adding them to P:

$$A3 = C\ (P + B50) \qquad \text{(Equation 4)}$$

---

5 It can be shown that the study of square area determinations by G. Chafaris can be summarized by an equation $A2 = C\ (P + 2\sqrt{P} + 1)$; "Area Computation From ERTS Data via Image-100" internal General Electric Co. report, 9 January 1975.

This method A3 is equivalent to a threshold classifier which adjusts the range of reflectance values such that exactly 50% of the border pixels are included as part of the pure class,

Results of mixed pixel area method A3 are summarized in Tables 1 and 2. Areas given for the USGS map were obtained by using a planimeter on each of the seven areas on a 1:24,000 scale map. The error in reproducibility for the planimetering was as small as 0.1% for the largest area and about 4% for the smallest area. These errors can all be considered negligible in comparison to the reproducibility obtained on the three different LANDSAT images given in Table 1[6]. Table 2 lists the number of pure water pixels, P; the number of border pixels, B50; the average area of the three dates, A3; and finally the percent error which was taken as the larger of either the precision or the accuracy of the mean of three measurements. Only in area 6, near the dam, is the apparent error of +10% significantly greater than expected error based on the progression from ±1% at 500 hectares to ±5% at 5 hectares. The reason for this apparent error near the dam seems to be that the planimetered area on the USGS map did not include the settling ponds below the dam and these were not separated out in calculating areas from the lists of LANDSAT images.

An area conversion factor, C, which converts pixel counts into area is required in all methods. For LANDSAT, it has a nominal value of 0.451 hectare/pixel, or 1.12 acre/pixel. This assumes that every pixel in every image is exactly the same 57m by 79m nominal size. When the location of the water body in the image is known, corrections can be made for the uneven scan rate of the satellite mirror across the scene and for the height of the satellite on different dates. R. Peterson[7] calculated the values of C for SCR for the three dates used in this study; they were 0.463, 0.459, and 0.459 hectare/pixel. In order to reduce these known systematic errors due to mirror velocity profile and different satellite heights, these values of C were used here even though there were not enough larger areas to determine the extent to which the conversion factors may have improved accuracy over the nominal value.

Reproducibility decreases with decreasing size, as illustrated by the percent standard deviations of a single measurement in Table 3. The comparison of pure and mixed pixel methods shows that the mixed method is always more precise. The random error in the

---

[6]The three LANDSAT images used for this area study were: 1692-15124 (15 June 1974), 1710-15120 (3 July 1974) and 1782-15092 (13 September 1974).

[7]R. Peterson, "Landsat Pixel Spacing-User Demonstration Projects Technique Report," preliminary General Electric Co. Report, 27 May 1975.

estimated area could be reduced further by taking the mean of several measurements.

Accuracy also decreases with decreasing size, although this is not so obvious in Table 4 because of the fortuitously close agreement of the mean of three dates for the smallest area when compared to the planimetered area from the 1:24,000 scale USGS map. The pure pixel method, A1, which makes no correction for border pixels, always underestimates the area. However, by estimating the border pixels from the number of pure pixels, pure pixel method A2 can be as accurate as the mixed pixel method for areas greater than about 20 hectares. If water areas smaller than this size are to be measured, then a mixed pixel method such as A3 must be used. Observed averages of the three dates and expected areas from the USGS map differed by less than the measured precision. There were no systematic deviations. Therefore it was concluded that the accuracy of a LANDSAT area measurement of water was limited solely by its precision.

The smallest area of water that can be measured by LANDSAT depends on the required precision. If one is talking about the ability to reproducibly <u>identify</u> the existence of a water body on every LANDSAT overpass, and if a pixel with about 30% water in it can be spectrally distinguished from land, then the minimum size for an identifiable body of water is approximately 0.5 hectare (1 acre). If one is comparing water areas for the same body on two different dates and looking for the smallest observable <u>change</u> at the 95% level of confidence (± 2 standard deviations), then the precision depends on the size of the body; e.g. two times ±8% at 5 hectares is ±0.9 hectare (±2 acres), whereas two times ±1% at 500 hectares is ±10 hectares (±25 acres). For some purposes the measurement of area might be useless unless it contained at least one "all water" pixel on every overpass, in which case the minimum sized area was shown to be about 2.5 hectares (6 acres). Above these lower limits, a user's required precision determines the smallest measurable body of water.

Since the mixed pixel method A3 was the most precise, two alternate techniques for calculating it were explored. One used a threshold classifier. The other used a contouring program. Both are theoretically identical to counting pixels from a computer list such as Figure 6, and therefore users can decide for themselves which technique is most convenient.

G.E.'s Image-100 was used to test the interactive threshold classifer. Two separate sets of threshold limits for MSS-7 were used as input to define the class bounds of pure water pixels and pixels with up to a certain percent water, taken as 50% in method A3. Then a polygon cursor was drawn around the area to be measured. Output was produced as an alphanumeric list of the two classes, similar to Figure 6, and two numbers were produced giving the total number of pixels in the two separate themes, pure and mixed pixels. A check of several areas on the alphanumeric list for a single date verified the agreement of this technique and the computer technique used for Figure 6.

Contouring was done with an IBM 360 Computer and a CALCOMP plotter. This technique requires that the final plot have the correct aspect ratio so that the area can be measured by planimetering the band 7 contour line corresponding to 50% water. Such a contour map of MSS-7 for SCR is shown in Figure 7. A contour map for water has several distinctive features. It requires no interaction with the user other than the choice of reflectance values for contour lines and therefore is relatively fast. Contouring programs are available on most general purpose computers as well as on several small stand-alone devices. Contour lines, like classifiers, emphasize certain

features and omit extraneous information. A contour map is an analog product which the knowledgeable user might be able to scan for subtle boundary changes without further processing; Figures 7 and 3 can be used to compare analog and digital presentations of band 7 reflectance values. The precision of calculating areas from contour maps was not evaluated here.

An example of a water inventory map is shown in Figure 8. It was prepared on an Image-100 classifier and printed as a black and white product on a DICOMED photographic recorder. One potential use of this map is to monitor the creation of new bodies of water; e.g. the three pronged lake in the center of the picture is a new feature that is not on existing maps of the area.

In summary, individual water areas can be measured from LANDSAT with an accuracy that decreases from ±1% at 500 hectares to ±8% at 5 hectares.

Assuming that pixels with more than 30% water can be identified from low MSS-7 reflectance values, total area measurements will be more accurate than single body measurements if most of the water is contained in a few large bodies which have relatively few border pixels. Furthermore, random errors in the calculation of the areas of each single body, caused by the inclusion of too many or too few mixed pixels, will cancel out when all single body areas are summed into one total area measurement. The absence of observable systematic errors suggest that water inventory maps from LANDSAT within some political or physical region might be accurate to ±1% in identifying the total area of open water. Although mixed pixel methods were more accurate than pure pixel methods, for some applications pure pixel methods might be adequate for areas above 20 hectares when a theoretical correction for border pixels is made.

DIRECT MONITORING OF WATER QUALITY

Ideally, VSWCB would like to monitor water quality directly with a sufficiently fast turn-around time to permit corrective action to be taken whenever possible. Detectors on LANDSAT were found to record reflectances which showed an inverse correlation with the depth one could see into the water (Secchi depth) and an apparent direct correlation with total solids. Since cloud-free LANDSAT coverage in Virginia occurred about once every 2 months, the utility of these correlations with turbidity appears to be primarily for monitoring changing water patterns and verifying the statistical appropriateness of ground-based sampling programs, rather than for monitoring water quality. This direct type of remote sensing information might permit more extensive monitoring of slowly changing water bodies than current limited budgets for field work permit.

Swift Creek Reservoir was the desired demonstration site for testing LANDSAT's capabilities because of forthcoming construction there. However, inspection of about 10 LANDSAT images taken over a two year period indicated relatively little within-image variation in reflectance values for any of the bands in the main portion of this reservoir. Therefore, Lake Chesdin Reservoir was added to the project because it tended to show much greater changes in reflectance values along its length.

Initial attempts to identify different types of water by using all four bands proved unnecessary for these two reservoirs. Using values averaged over six lines to remove differences in reflectance due to unequal sensor calibration, locations in both SCR and LCR showed correlations among bands 4, 5, and 6 on all seven cloud free LANDSAT images that were analyzed in detail. For the 13 Sept 74 image, the range of MSS-5 reflectance was arbitrarily sliced into seven approximately equal sections and the limits of each of these were used as threshold inputs to form classes on G.E.'s Image-100. Then, the mean values of the other three bands were calculated for each of the 7 classes. The

resulting band correlations are shown in Figure 9. There was a 99% linear correlation among bands 4, 5, and 6. Only MSS-5, which showed the largest range of the three, was used in subsequent classification work on these two reservoirs.

It seems likely that only one water quality parameter, such as turbidity, is causing all the observed changes in reflectances. Reflectances from bands 4, 5, and 6 are nearly perfectly correlated in LCR. If reflectances were being increased or decreased by more than one agent, it is unlikely that the proportional changes would be the same in all three bands.

13 Sept 74 was the LANDSAT image date chosen for making a water classification map because it was the only cloud-free date available for which significant ground truth was collected in LCR. A map of the seven band-5 level-sliced classes for the region SW of Richmond is given in Figure 10. The water in SCR is essentially in one class, except for some striping due to unequal sensor calibration on the satellite. Figure 11 is a blown-up portion of Figure 10 showing only LCR. Water of the same low reflectance as SCR can be seen in the southwest part of LCR. This low reflectance region had been noted on many previous images and personnel at VSWCB were unaware that two types of water existed in this part of LCR. It turned out that this was the place where Namozine Creek entered LCR, as seen in a U-2 photograph (Figure 12). The narrow flow of water under a small bridge produced a dramatic low reflectance water class coming into the highly reflectant sediment-laden water of Lake Chesdin. Figure 13 shows what this interface looked like from a VSWCB boat on 13 Sept 74. Another small tributary of low reflecting water entering LCR can be seen in Figure 11 to the east. This is Whipponock Creek. As a result of these observations from LANDSAT, a water sampling program has been proposed for VSWCB based on the locations of different types of water. It is particularly valuable for VSWCB to have information on the far western end of LCR from LANDSAT since this area is almost inaccessible by boat.

Having established that different types of water could be directly observed from LANDSAT, the question became one of trying to identify the water quality parameter most likely responsible for the changes in reflectance. For more than a year, extensive water quality measurements were made on water samples from SCR. However, since differences in LANDSAT reflectances were not observed in the main portion of SCR, no conclusion could be drawn except that observed variations in water quality were small and below the limit of detection from LANDSAT.

Secchi depth measurements taken by NASA and VSWCB personnel in LCR on 13 Sept 74 provided the first and only set of data where there was significant variation in both the LANDSAT and ground data to check for a possible correlation. Figure 14 shows the 98% inverse correlation of:

$$\text{Reflectance} = 32.1 - 0.22\ \text{Secchi} \qquad \text{(Equation 5)}$$

If one thinks in terms of using this as a calibration curve for estimating Secchi depths in other parts of the map, then the equation can be rearranged to make reflectance in MSS-5 the independent variable:

$$\text{Secchi} = 143.5 - 4.41\ \text{reflectance} \qquad \text{(Equation 6)}$$

Sixteen individual Secchi measurements were made, but the average Secchi value was used in each class to calculate Equations 5 and 6, in order to give equal statistical weight to all reflectances and not to bias the equation in favor of the area in which most of the data was taken. Furthermore,

the use of only four numbers emphasizes the lack of data at low reflectances here and therefore the need to treat these equations as illustrative rather than definitive.

Three samples of water were also taken from LCR on 13 Sept 74. Laboratory measurements were made for the "volatile" (organic) and "fixed" (inorganic) fractions of both the "total solids" and the "suspended solids" content of samples. Reflectance is generally considered as being correlated with suspended solids; however, in LCR the particulate matter was nearly colloidal and 90% of total solids passed through the standard filter used for the suspended solids. There was an approximately equal contribution from the volatile and fixed fraction of the total solids and no correlation was found between the sum of the two fractions, namely the "total solids" and MSS-5.

The three values for total solids were 78, 82, and 92 mg/l, where the respective average gray level intensities for MSS-5 reflectance were 11.5, 21.5, and 25.8. This gives an 89% coefficient of correlation for:

$$\text{Total Solids} = 66.8 + .88 \text{ reflectance} \qquad \text{(Equation 7)}$$

It must be recognized that the total solids data, while perhaps more fundamental, is less statistically significant than the Secchi depth data because the former is based on only three water samples.

In summary, LANDSAT reflectances from water in the visible (MSS-4 and MSS-5) and near-infrared (MSS-6) spectral bands were shown to be spectrally and spatially coherent for both SCR and LCR, which is larger, narrower, and has a ten times greater flow rate than SCR, due to input from the Appomatox River. Maps of different reflectances in water could be derived using only MSS-5 values for these two reservoirs since it appeared that only total solids content was changing reflectances. The high correlation of Secchi depth and MSS-5 in LCR may be due to Secchi depth measurements being dependent on total solids. Since both the size and type of particle affects reflectance, it is expected that calibration equations of LANDSAT reflectance and a water quality parameter will be necessary for each region which supplies different organic and inorganic materials from its watershed. For LCR it was possible to distinguish classes of water from LANDSAT imagery which differed by about 5cm at the most sediment-laden and reflective Secchi depths. Direct monitoring of water quality from LANDSAT seems to be most useful for observing changes in water patterns and devising and verifying water sampling programs.

INDIRECT MONITORING - LAND COVER

Perhaps the greatest potential contribution of LANDSAT to a water quality monitoring program is through indirect interpretation, by detecting changes in land cover in a watershed. Surface alterations, such as deforestation or increase in agricultural use, may cause water quality changes due to increased runoff, pollutant input and other factors. The purpose of this section is to demonstrate both qualitative and quantitative means of monitoring land cover with LANDSAT.

One digital product that can be prepared from LANDSAT CCT's is a color composite of a subsection of the whole 185 km by 185 km image. Figure 15 is a picture of the 30 km by 30 km area surrounding SCR. It was prepared on a DICOMED printer. Geometric corrections were made to the picture on GE's Image-100 and an IBM 360 computer to correct for rotation of the Earth during satellite overpass (skew correction) and for the rectangular shape of pixels (aspect ratio correction). Without further processing, this picture can be scanned by people familiar with the area to see if there have been any major changes in land cover. For the knowledgeable expert, this picture provides more information than a classed image.

If it is necessary to quantify the extent of change in land cover, rather than simply identify that a change has occurred, then it is necessary to classify the image. This was done in several ways, one of which was using the normal threshold classifier on G.E.'s Image-100. One of the steps was to limit the area being classed on the LANDSAT image to the acreage inside the Swift Creek Reservoir watershed, shown in Figure 16. The resulting classification maps for 15 June 74 and 13 Sept 74 are given in Figures 17 and 18.

A check on the accuracy of the classification was made by visually classifying a U-2 photograph and checking the above classifications pixel-by-pixel with a zoom-transfer scope in 5 sites that were known to be unchanged. The results of these two checks are given in Tables 5 and 6. The thin cloud cover on 15 Jun resulted in 14% of the pixels being unclassed whereas only 5% were unclassed on the 13 Sept image. Clouds also interfered with the identification of all agricultural land on 15 June. This watershed is about 70% forest and it was impossible to find large homogeneous training sites for the non-forest classes on either date. Therefore these classes have a lower value in the accuracy table.

The overall results for the two dates have been summarized in Table 7. The "agriculture" class includes pixels which are mixtures of forest and open areas cleared for construction.

The area of the Brandermill construction site inside the watershed can be seen as the non-forest area north of the reservoir in the 13 Sept 74 classed image (Figure 18). One of the white "barren" class pixels near the water was identified in a low altitude aircraft photograph as containing several piles of white sand for a golf course.

In summary, changes in land cover classes can be monitored from LANDSAT. Useful integration of this information into predictions of changes in water quality is probably several years off and must await the development of quantitative models for the watershed. In the meantime, such maps and tables can alert personnel such as the VSWCB to possible changes in water quality. The observation of the Brandermill site before and after the start of construction illustrates the ability of LANDSAT to not only produce land

cover maps, but to monitor changes in land cover.

ACKNOWLEDGEMENT

This demonstration project could not have been completed without the scientific and technical assistance of Peter Trexler and Clark Thaler of the Division of Surveillance and Field Studies, Piedmont Regional Office of the Virginia State Water Control Board and Dorothy Schultz of General Electric's Beltsville, Maryland office.

TABLE 1 REPRODUCIBILITY OF MEASUREMENTS FROM LANDSAT

AREAS OF WATER (in Hectares)				
LOCATION	USGS MAP	LANDSAT		
		JUNE '74	JULY '74	SEPT '74
5	464.7	476.2	463.0	469.6
3	75.2	78.4	73.0	77.2
6	30.8	33.5	34.0	33.8
2	25.5	24.8	23.4	25.9
4	22.1	22.2	21.6	22.7
1	10.9	11.1	9.4	10.2
7	5.5	5.0	5.5	5.9

TABLE 2 ACCURACY OF AVERAGED AREA MEASUREMENTS FROM LANDSAT

AREAS OF WATER					
LOCATION	USGS MAP	LANDSAT			
	AREA Hectares	WATER Pixels	BORDER Pixels	AREA Hectares	ERROR %
5	464.7	902	118	469.6	± 1
3	75.2	117	49	76.2	± 2
6	(30.8)	53	20	33.8	±10
2	25.5	30	24	24.7	± 3
4	22.1	31	17	22.2	± 2
1	10.9	2	17	10.2	± 5
7	5.47	1	11	5.5	± 5

TABLE 3 REPRODUCIBILITY OF AREA MEASUREMENTS

Method	Percent Precision (by size)		
	at 500 hectares	at 25 hectares	at 5 hectares
Pure Pixel	± 3%	± 8%	---
Mixed Pixel	± 1%	± 4%	± 8%

TABLE 4 ACCURACY OF AREA MEASUREMENTS

Method	Percent Deviation (by size)		
	at 500 hectares	at 25 hectares	at 5 hectares
Pure Pixel, A1	-10%	-40%	-90%
Pure Pixel, A2	+ 1%	+ 2%	-60%
Mixed Pixel, A3	+ 1%	- 2%	(+.1%)

TABLE 5 LANDSAT CLASSIFICATION COMPARED WITH KNOWN LAND COVER

PERCENT ACCURACY OF CLASSIFICATION									
	JUNE 74 LANDSAT-1								
U-2	WAT	W/L	PIN	HDW	AGR	BAR	RES	UNCL	MIS-CLSD
WATER	97	3	0	0	0	0	0	0	3
WATER/LAND	0	46	14	0	9	0	0	31	23
PINE	0	0	82	3	3	0	0	12	6
HARDWOOD	0	0	15	62	5	0	0	18	20
AGRICULTURE	0	0	4	1	54	2	4	35	11
BARREN	0	[illegible]	2	0	9	62	21	6	32
RESIDENTIAL	0	0	10	5	38	12	11	24	65

TABLE 6 CHANGED LANDSAT CLASSIFICATION AFTER 3 MONTHS

PERCENT ACCURACY OF CLASSIFICATION									
	SEPT 74 LANDSAT-1								
U-2	WAT	W/L	PIN	HDW	AGR	BAR	RES	UNCL	MIS CLSD
WATER	97	3	0	0	0	0	0	0	3
WATER/LAND	0	46	17	1	1	0	0	35	19
PINE	0	0	80	9	4	0	0	7	13
HARDWOOD	0	0	30	61	6	0	1	2	37
AGRICULTURE	0	0	3	11	50	0	17	20	30
BARREN	0	0	0	0	11	34	39	16	49
RESIDENTIAL	0	0	2	1	50	1	36	10	54

TABLE 7 COMPARISON OF LAND COVER CLASSES FOR SWIFT CREEK RESERVOIR AND BRANDERMILL CONSTRUCTION SITE

LAND COVER CLASSES IN PERCENT				
	18,000 HECTARE BASIN		740 HECTARE CONSTRUCTION SITE	
	JUNE	SEPT	JUNE	SEPT
PINE	38	38	65	51
HARDWOOD	33	35	16	17
AGRICULTURE	9	15	4	18
RESIDENTIAL	2	4	1	2
BARREN	1	0	0	1
UNCLASSED	14	5	10	6
WATER	3	3	4	5

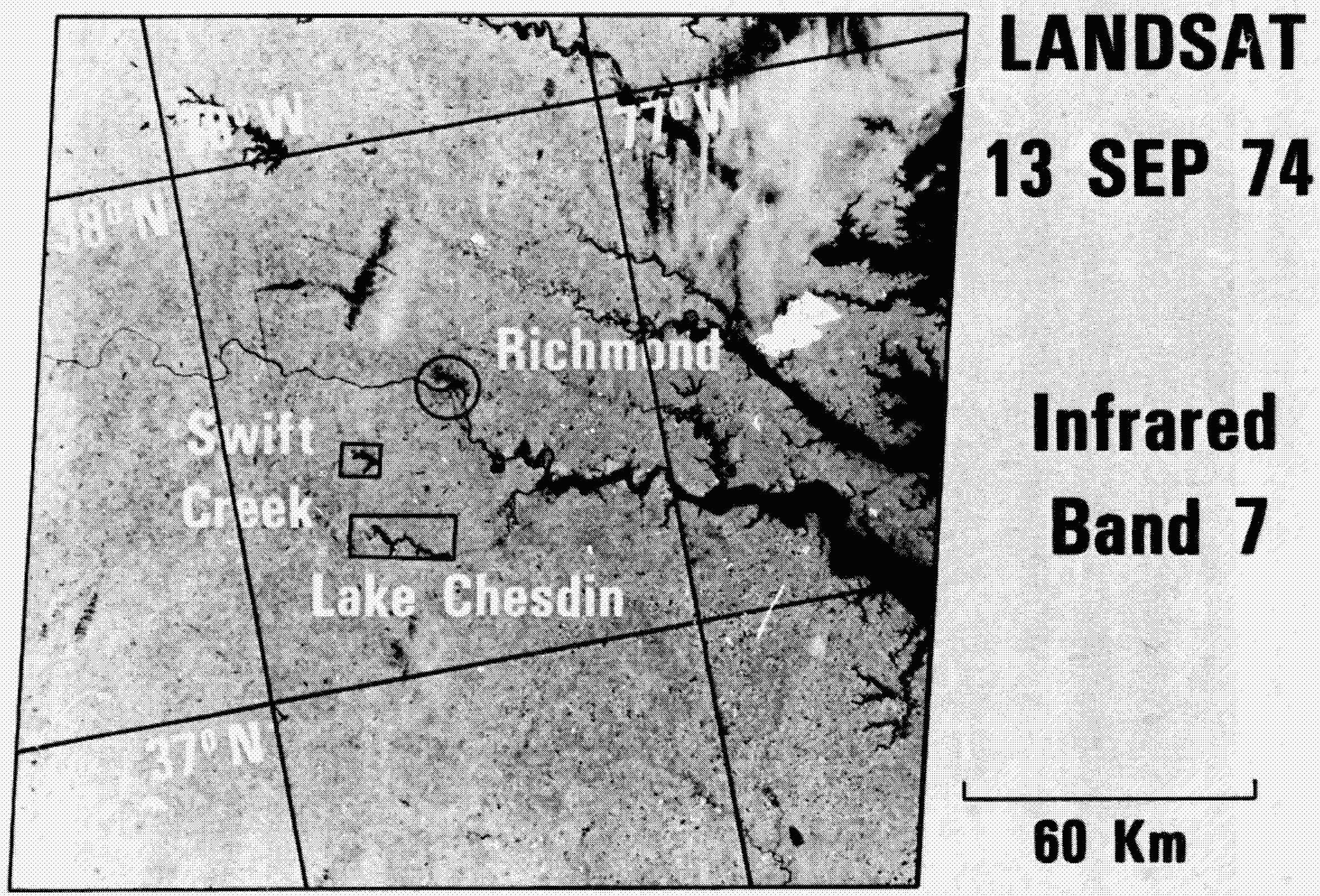


Figure 1.- Annotated print of standard 8.5 cm x 8.5 cm NASA LANDSAT negative.

Figure 2.- Photographic blow-up of Swift Creek Reservoir, Virginia from standard 8.5 cm x 8.5 cm LANDSAT negative.

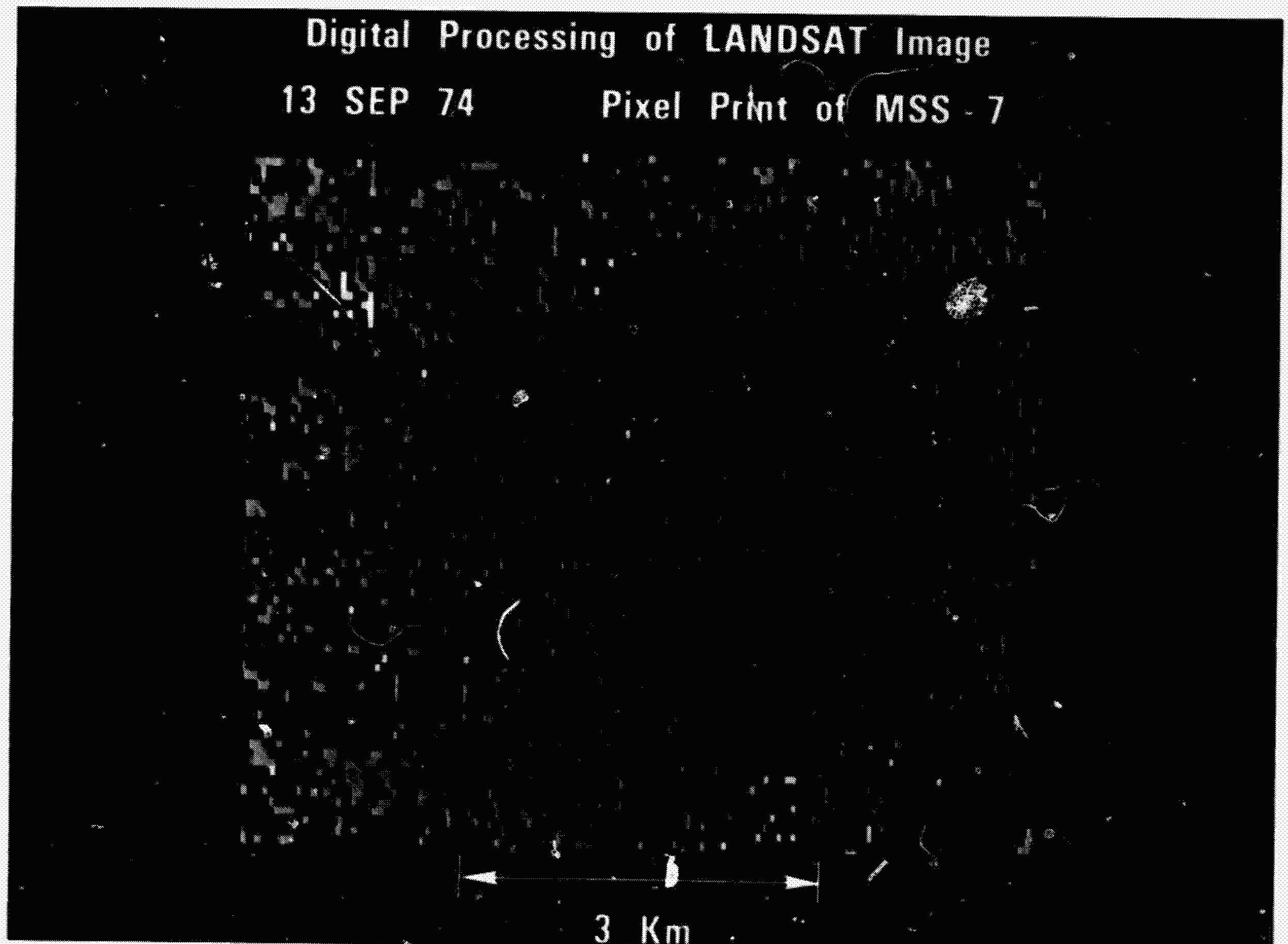


Figure 3.- Pseudo-color pixel print of Swift Creek Reservoir, Virginia from LANDSAT CCT, illustrating potential for viewing every pixel and every reflectance value.

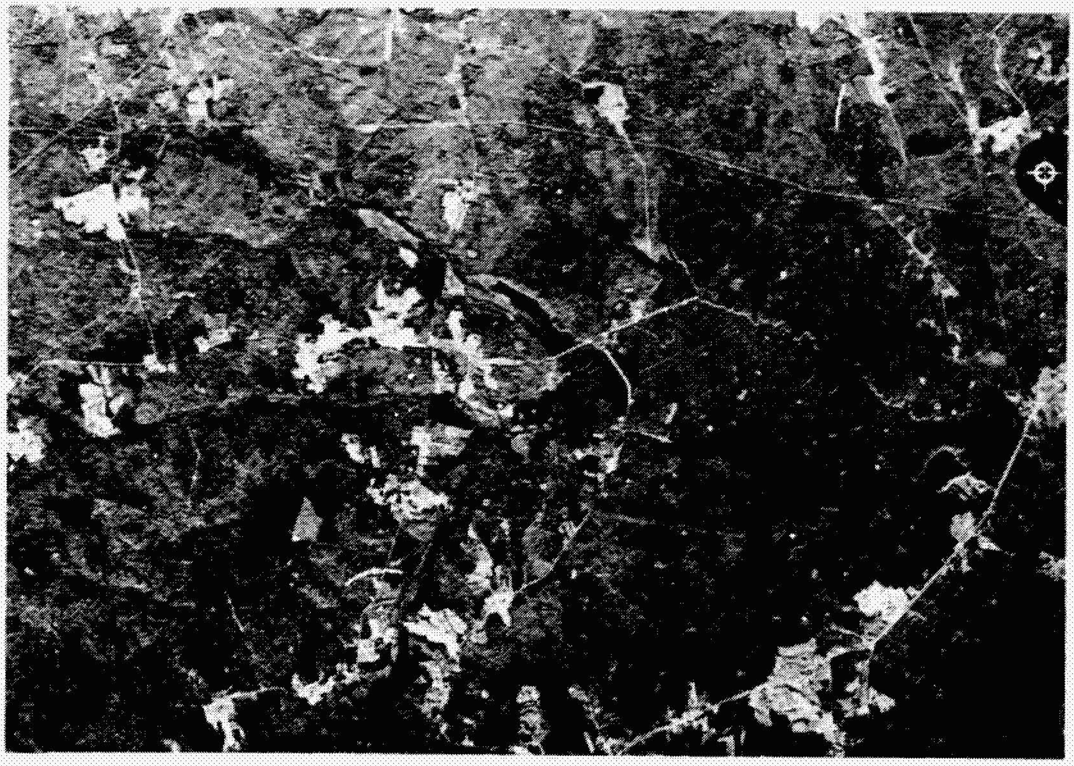


Figure 4.- U-2 photograph taken at 60,000 feet. Locations of 7 sections of Swift Creek Reservoir, used in checking precision and accuracy of area measurements from LANDSAT, are shown in Figure 5 and 6.

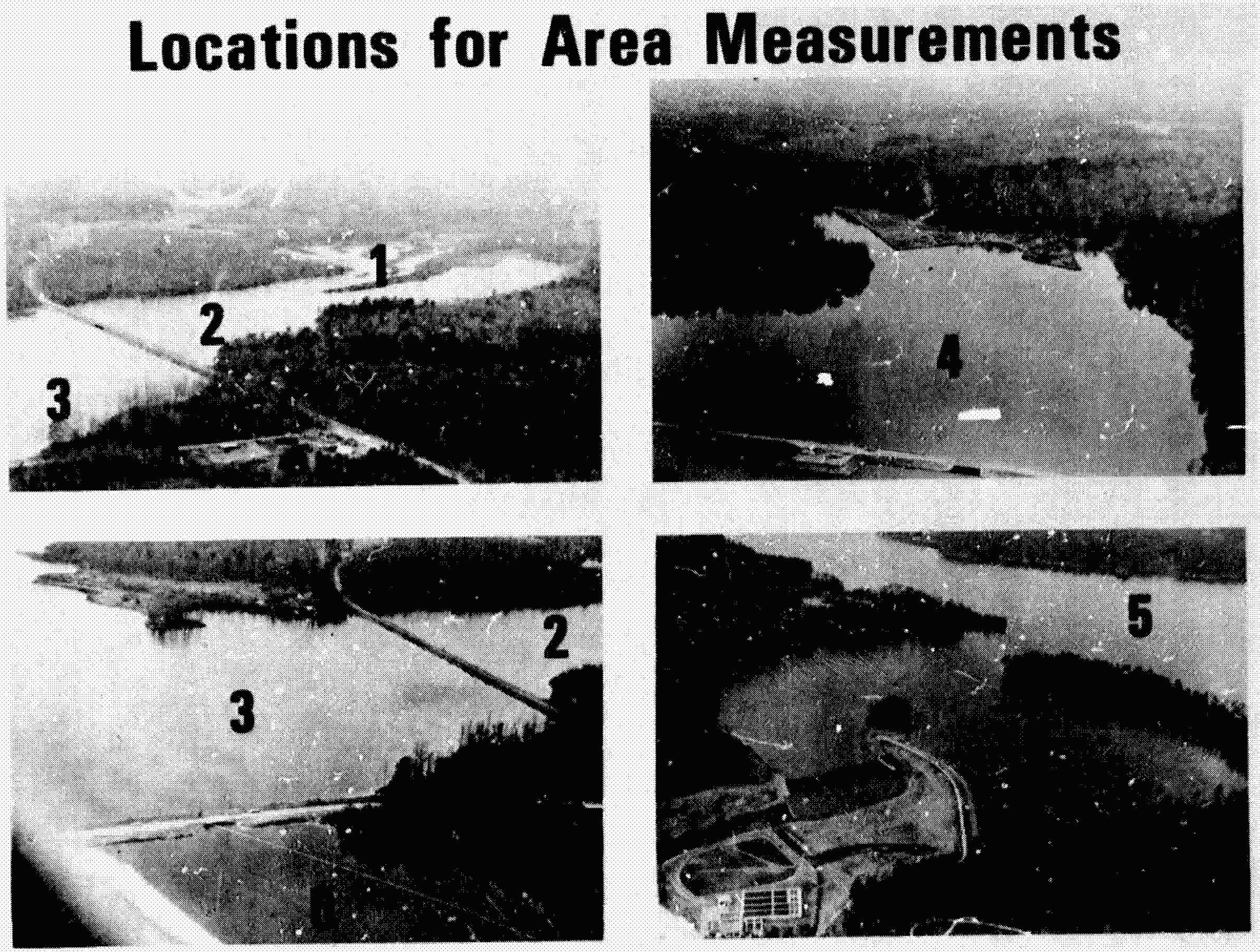


Figure 5.- Low altitude Kodachrome prints of some of the 7 sections of Swift Creek Reservoir used for area measurements.

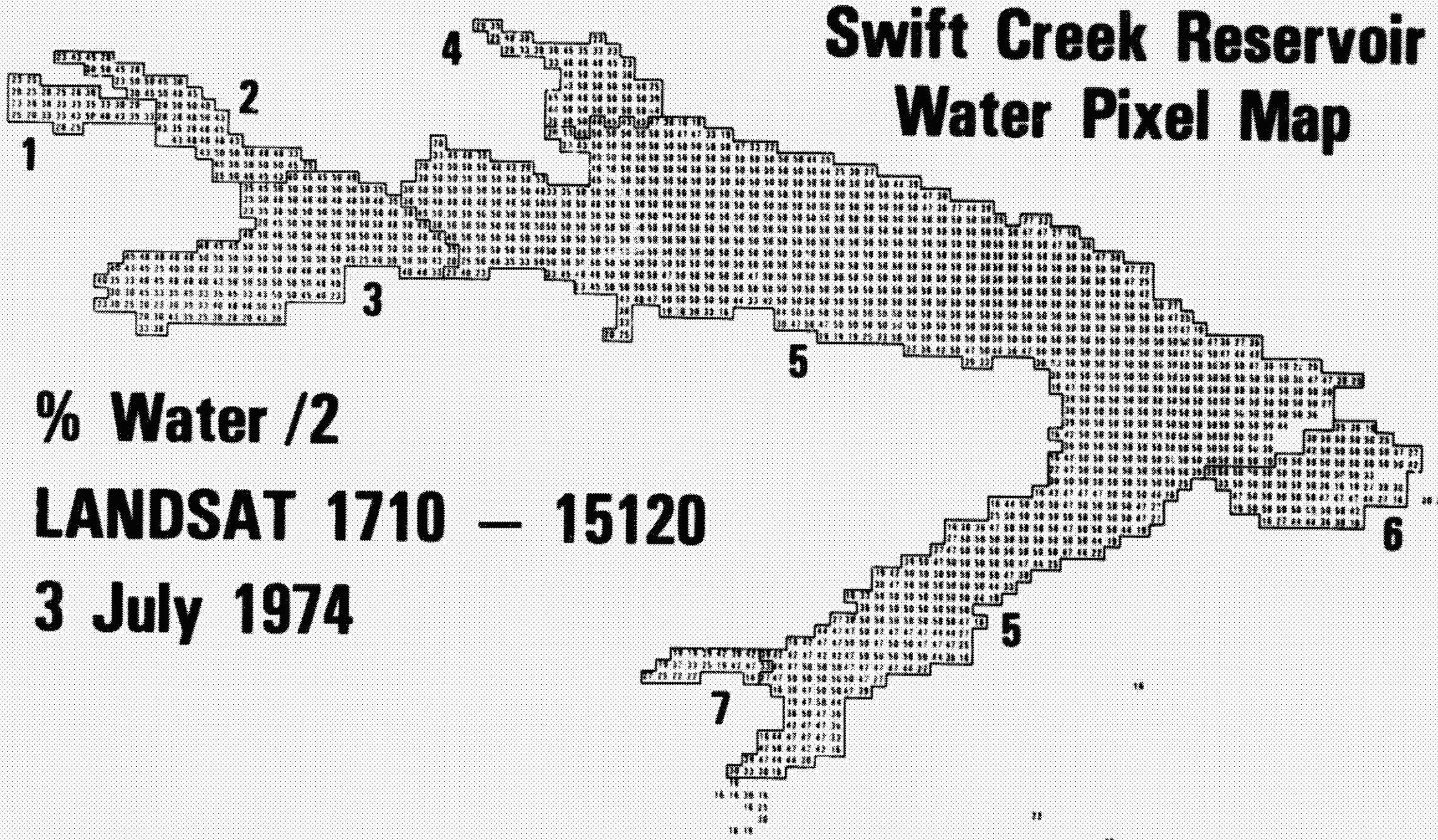
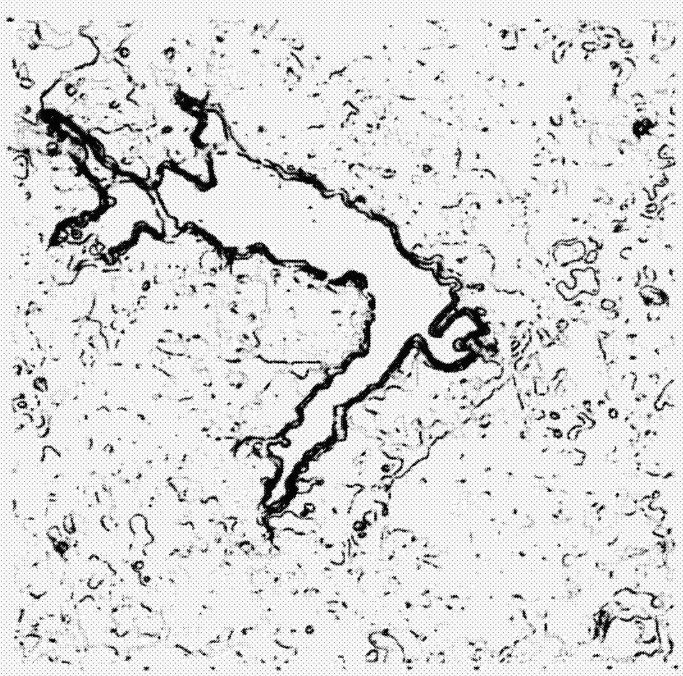


Figure 6.- Computer list of MSS-7 reflectance values of Swift Creek Reservoir converted to percentage of water divided by 2 showing 7 sections used for area measurements.



MSS-7
CONTOUR MAP

13 SEP 74
1782 - 15092

SWIFT CREEK
RESERVOIR

Figure 7.- CALCOMP contour map of Swift Creek Reservoir for selected values of MSS-7 chosen to emphasize the boundary between land and water.

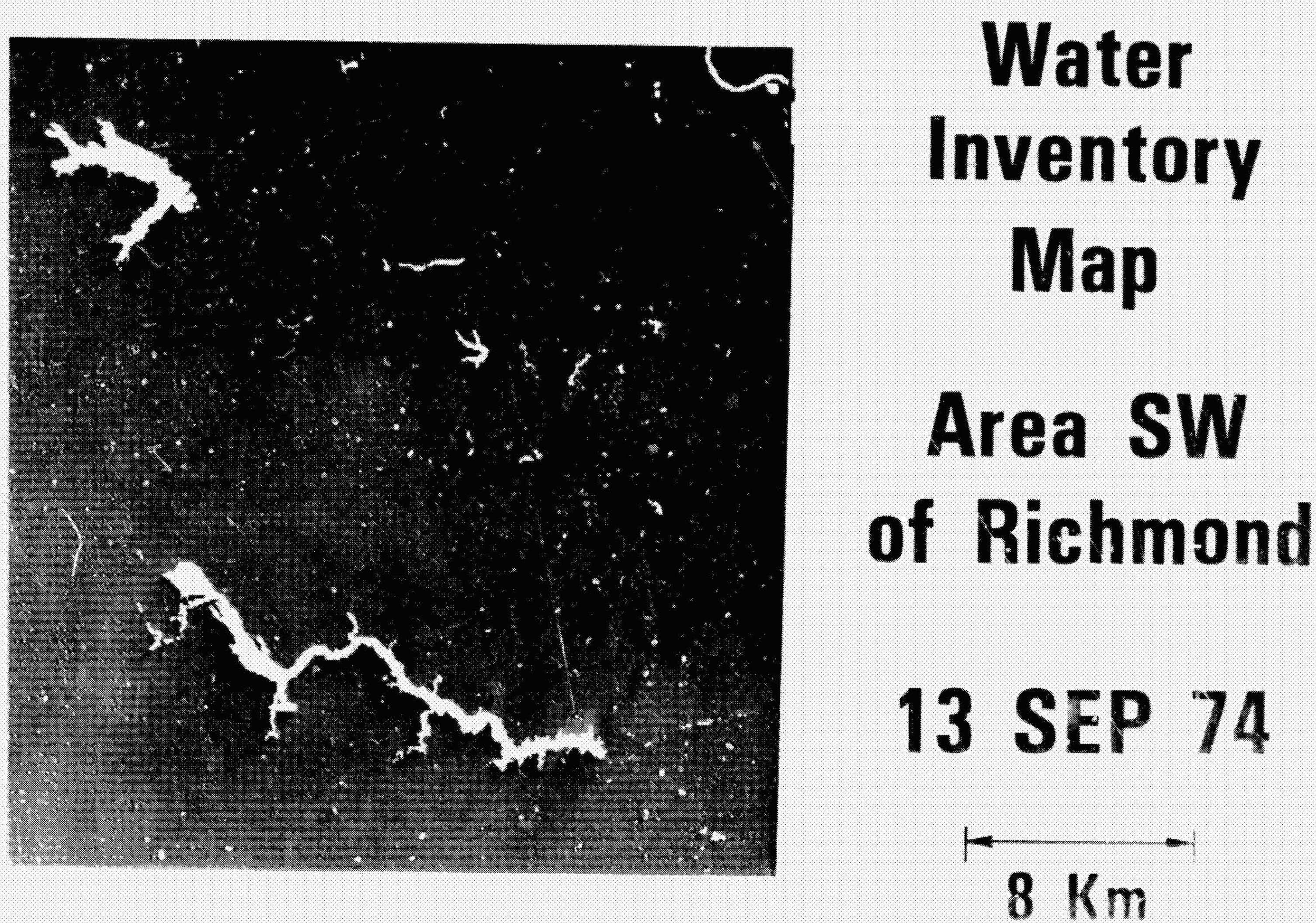


Figure 8.- Water inventory map of a 30 Km by 30 Km region SW of Richmond derived from a LANDSAT image by identifying all pixels which contained more than approximately 60% water.

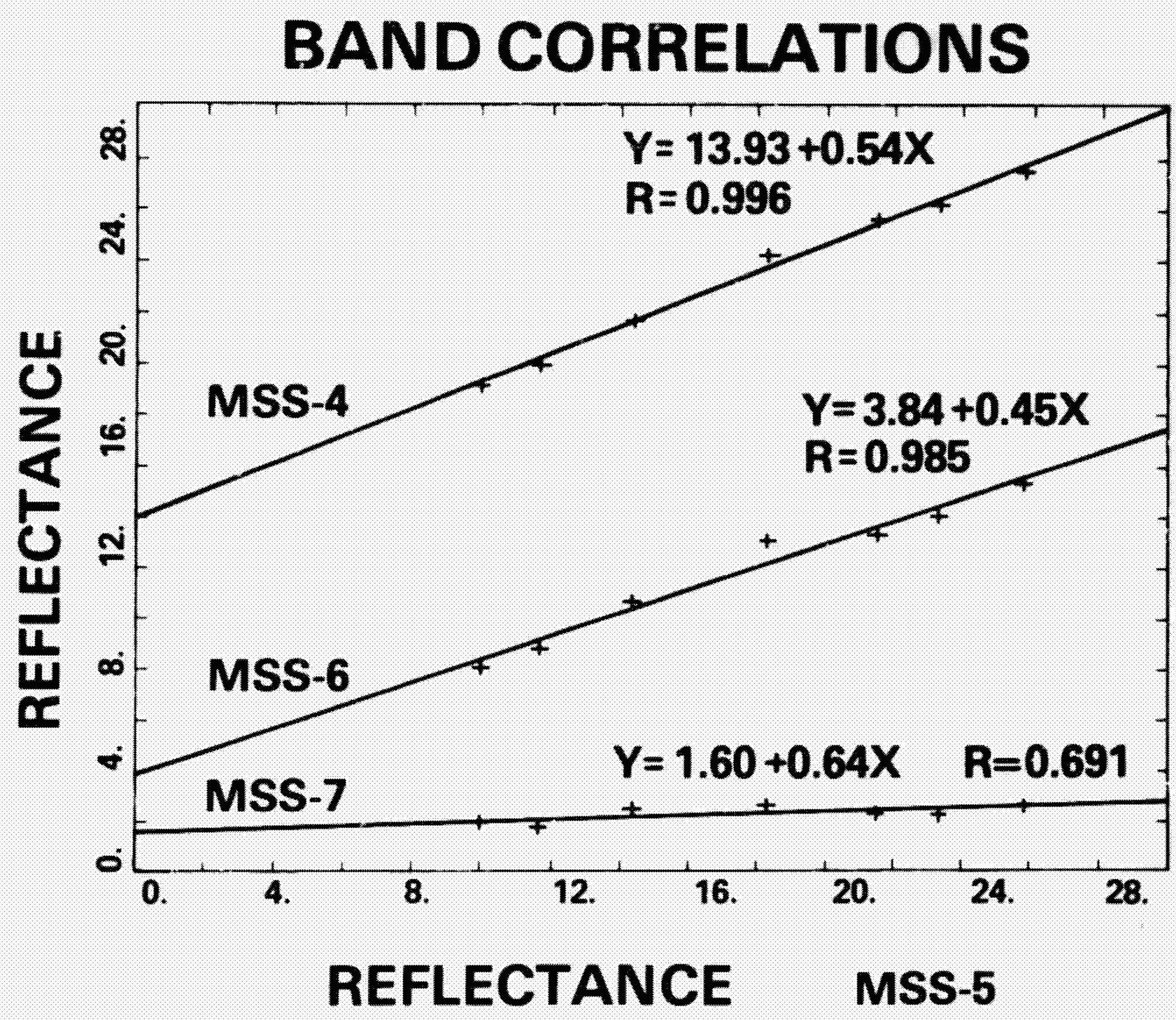


Figure 9.- Correlation of LANDSAT reflectances from water in different MSS bands on 13 Sept 74 in Swift Creek and Lake Chesdin Reservoirs.

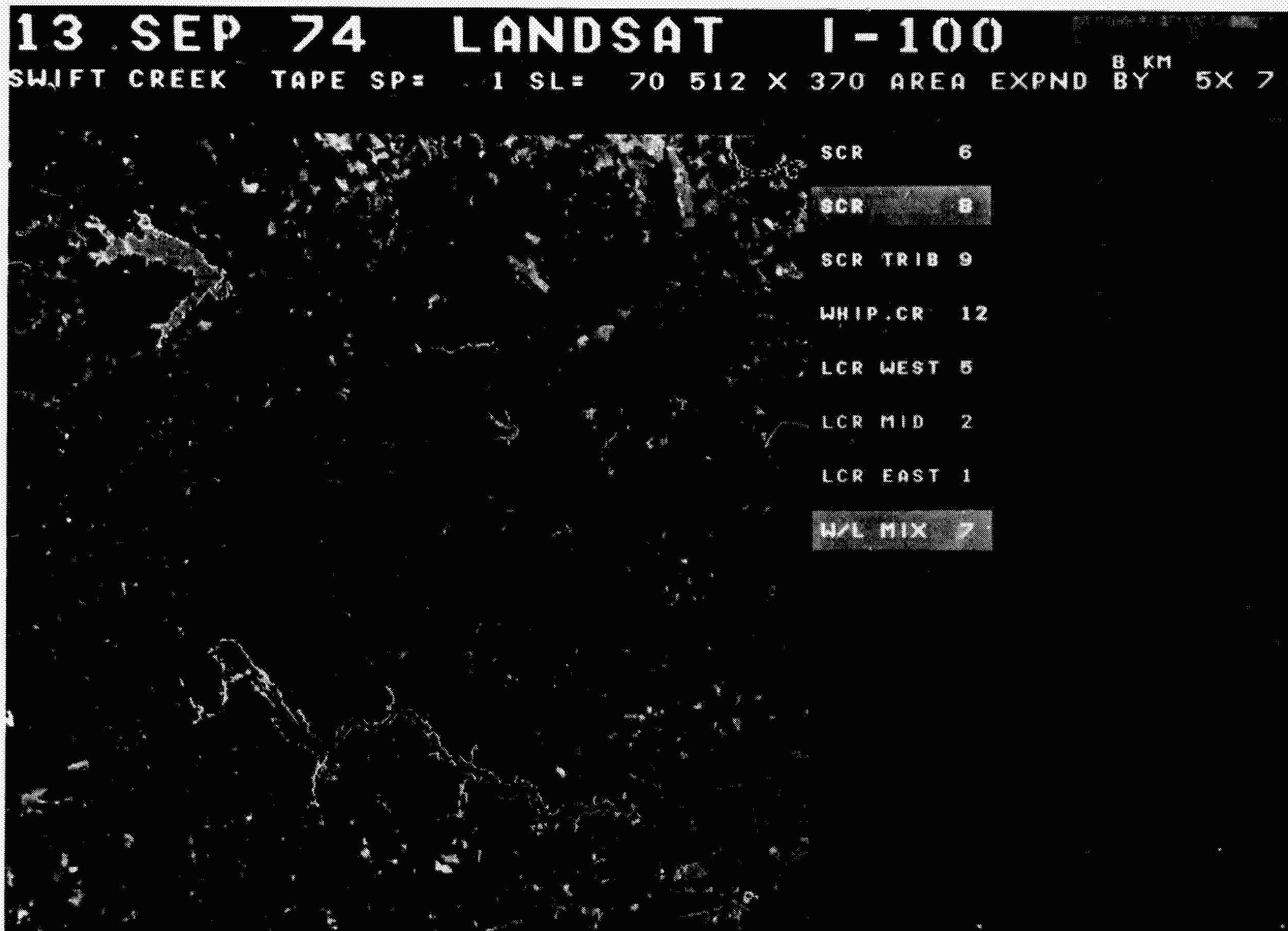


Figure 10.- Map of seven MSS-5 level-sliced water classes for 30 Km by 30 Km region SW of Richmond on 13 Sept 74.

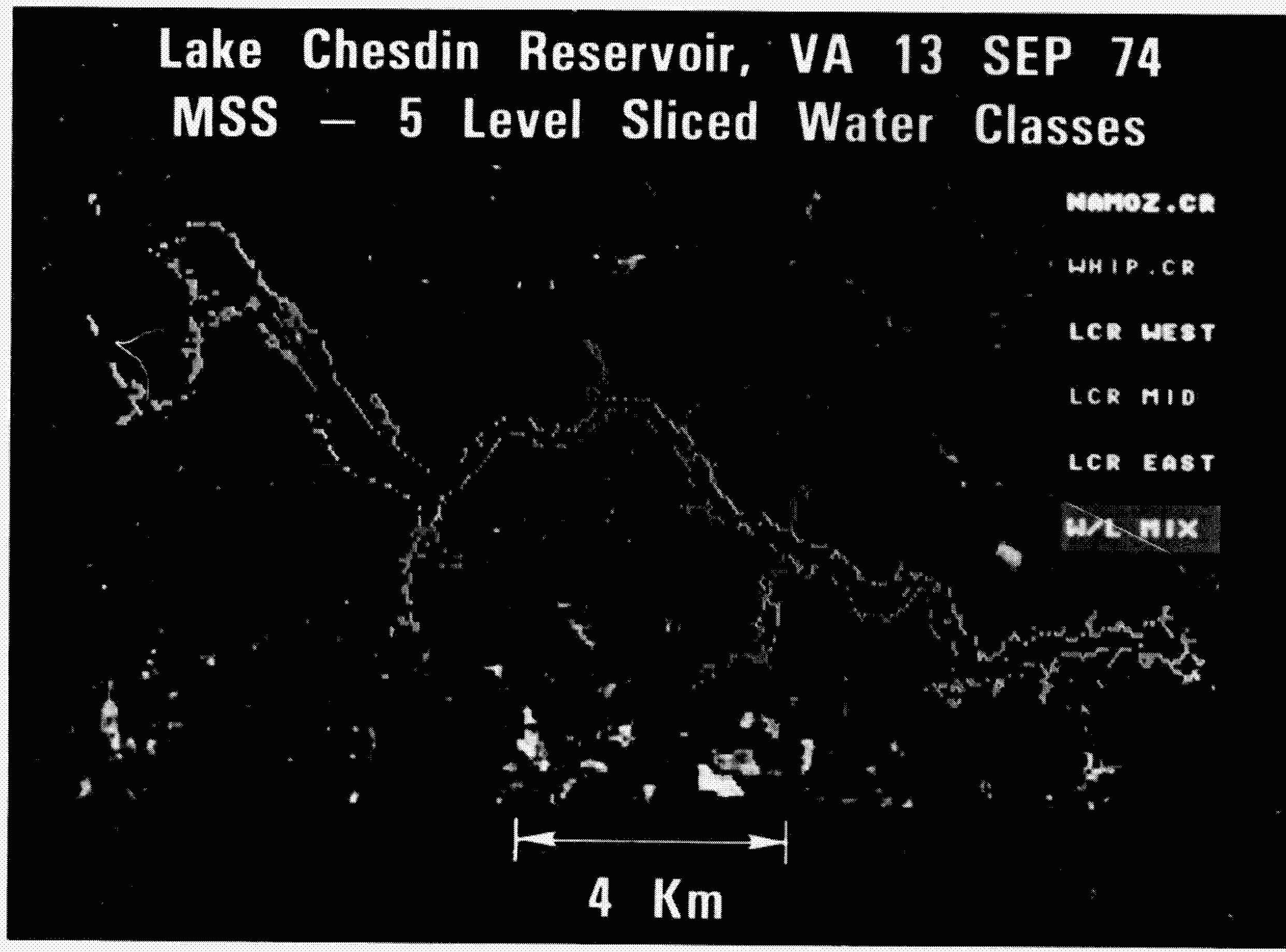


Figure 11.- Map of seven MSS-5 level-sliced water classes in Lake Cherdin Reservoir on 13 Sept 74.

Figure 12.- Blow-up of 2 Dec 72 U-2 photograph showing southwestern part of Lake Chesdin where Namozine Creek enters.

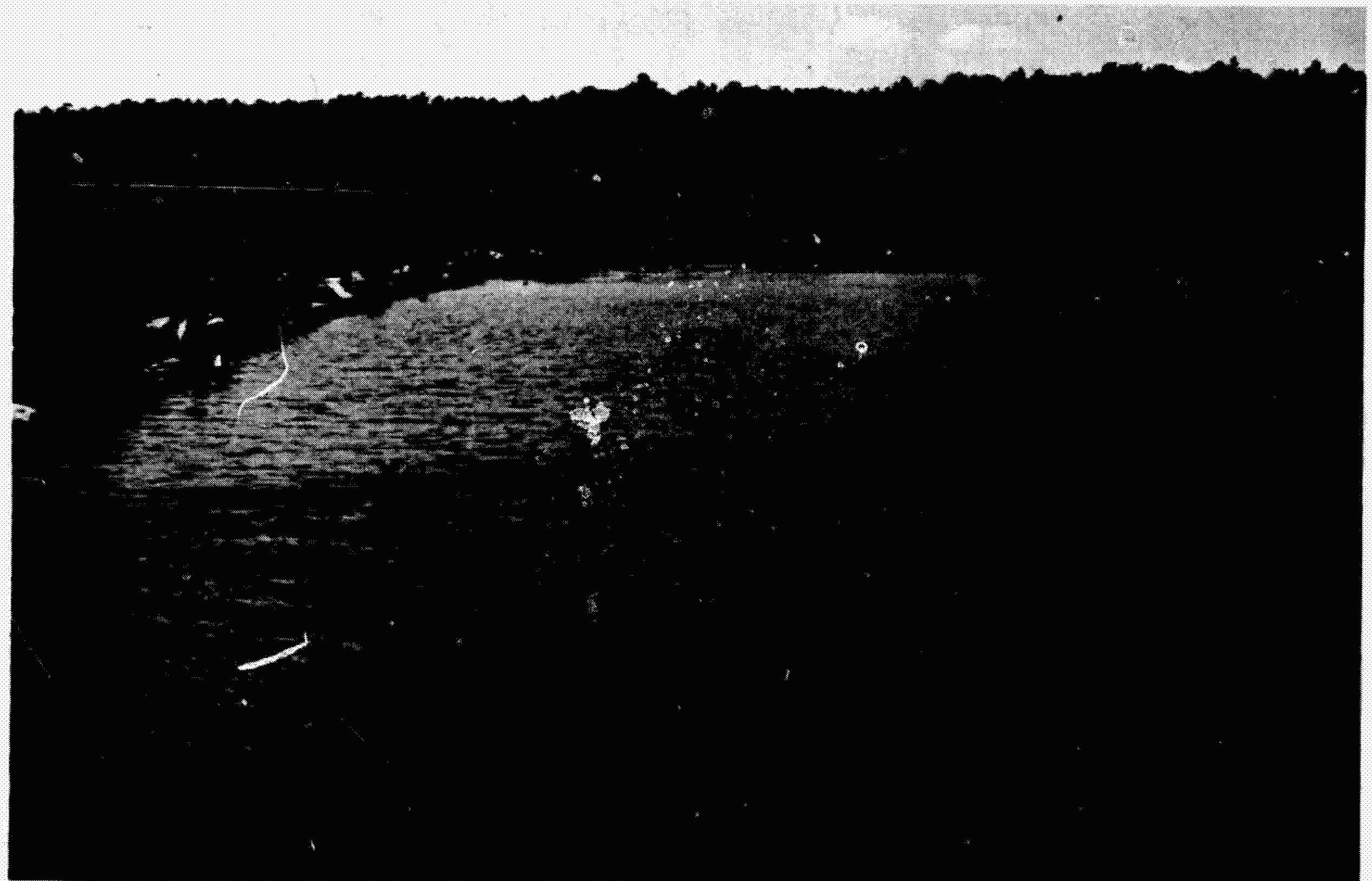


Figure 13.- Ground level picture of interface boundary between clear water from Namozine Creek and sediment-laden water in Lake Chesdin on 13 Sept 74.

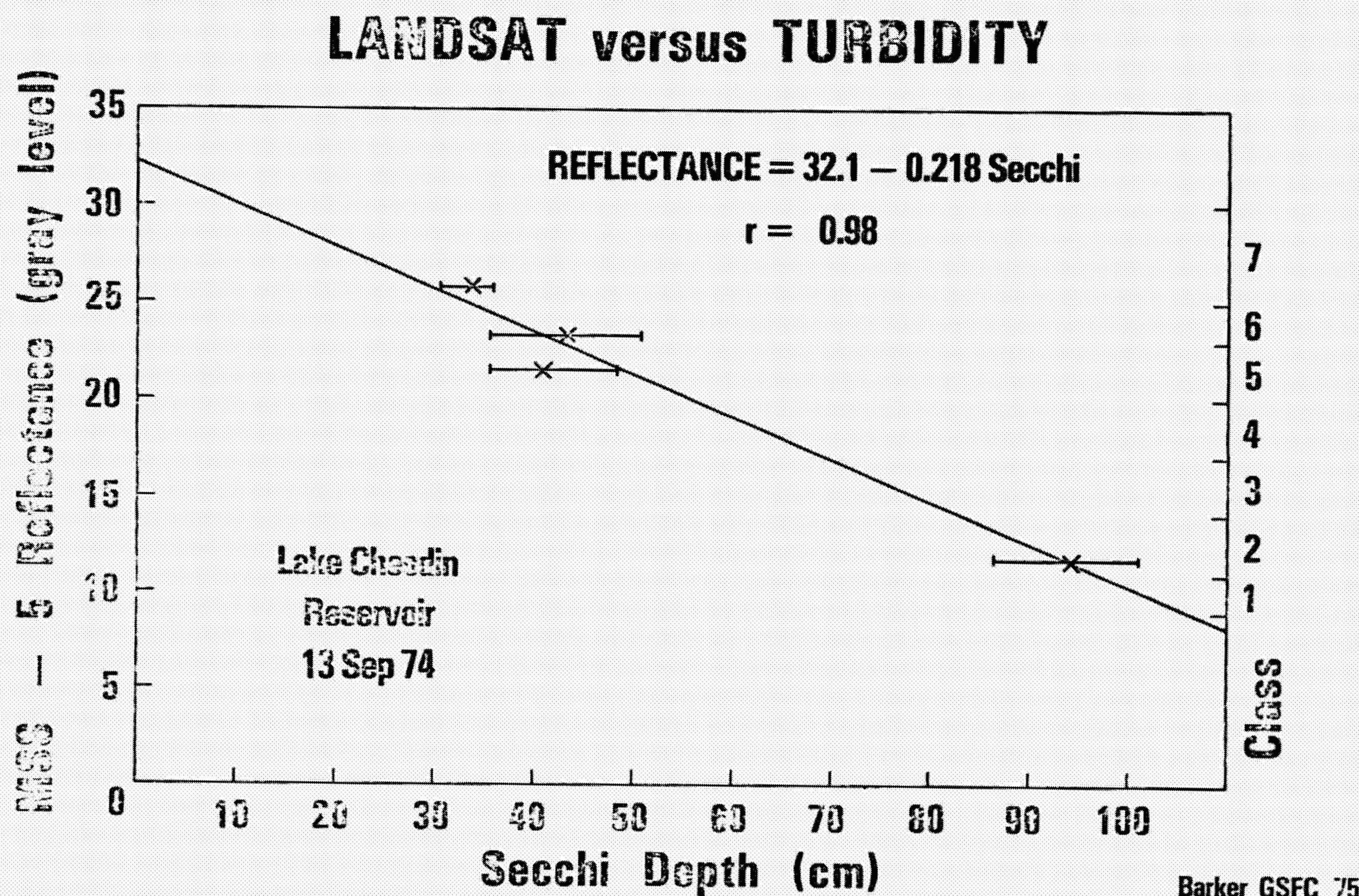


Figure 14.- 98% correlation of LANDSAT MSS-5 reflectance with Secchi depth in Lake Chesdin Reservoir on 13 Sept 74.

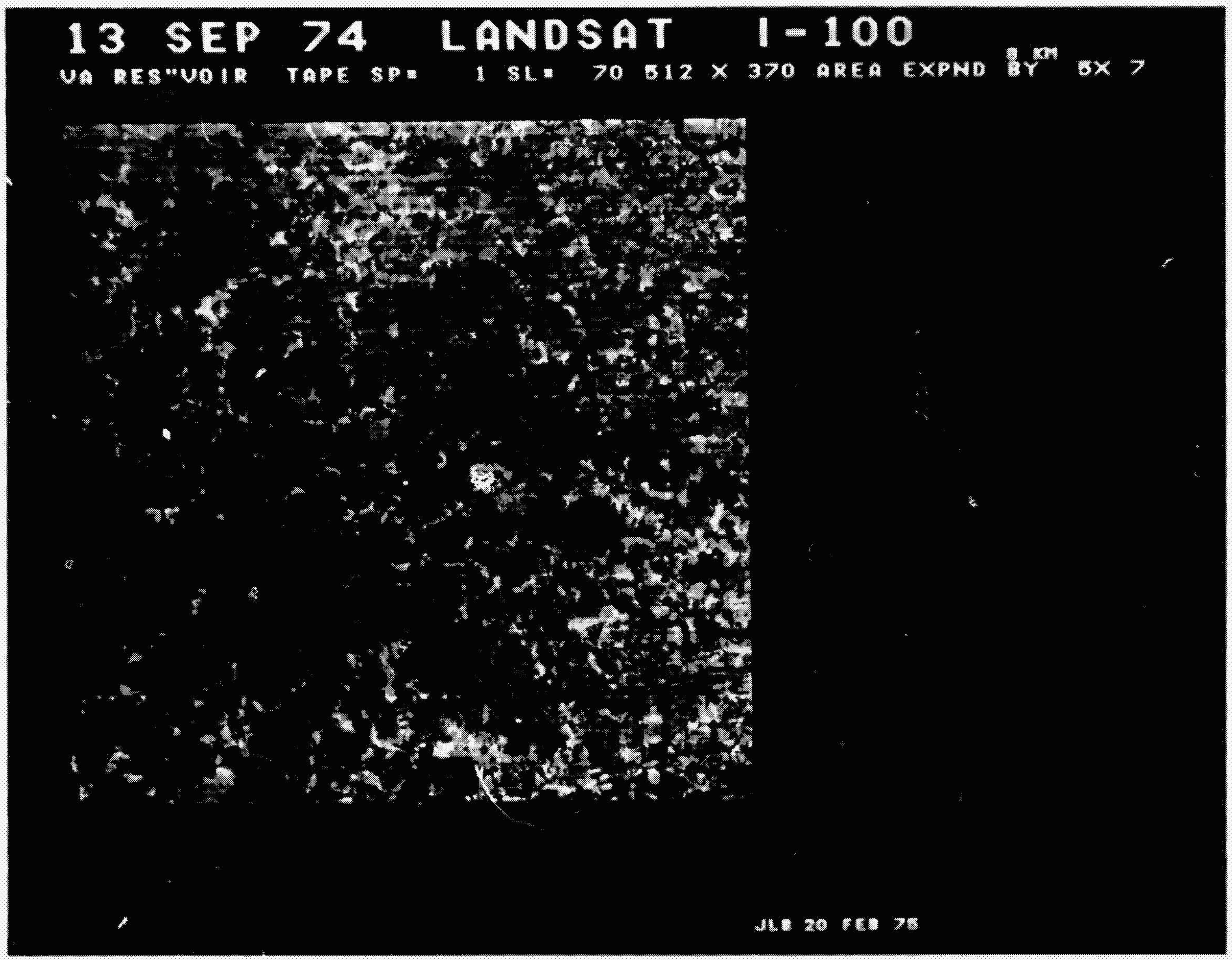


Figure 15.- Color composite of LANDSAT bands 4, 5, and 7 of 30 Km by 30 Km area around Swift Creek Reservoir on 13 Sept 74.

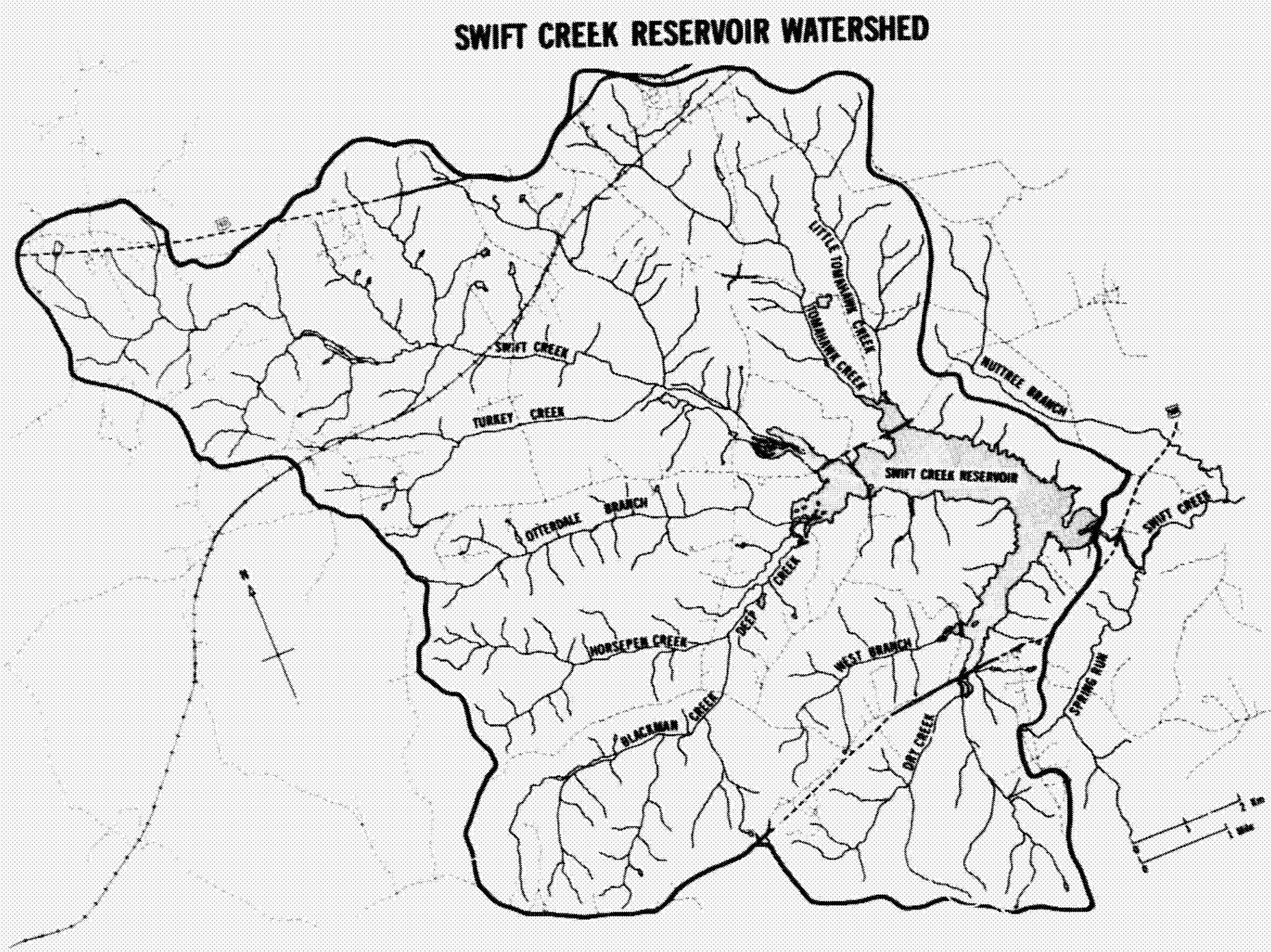


Figure 16.- Swift Creek Reservoir Watershed traced from contours on 1:24,000 scale USGS map.

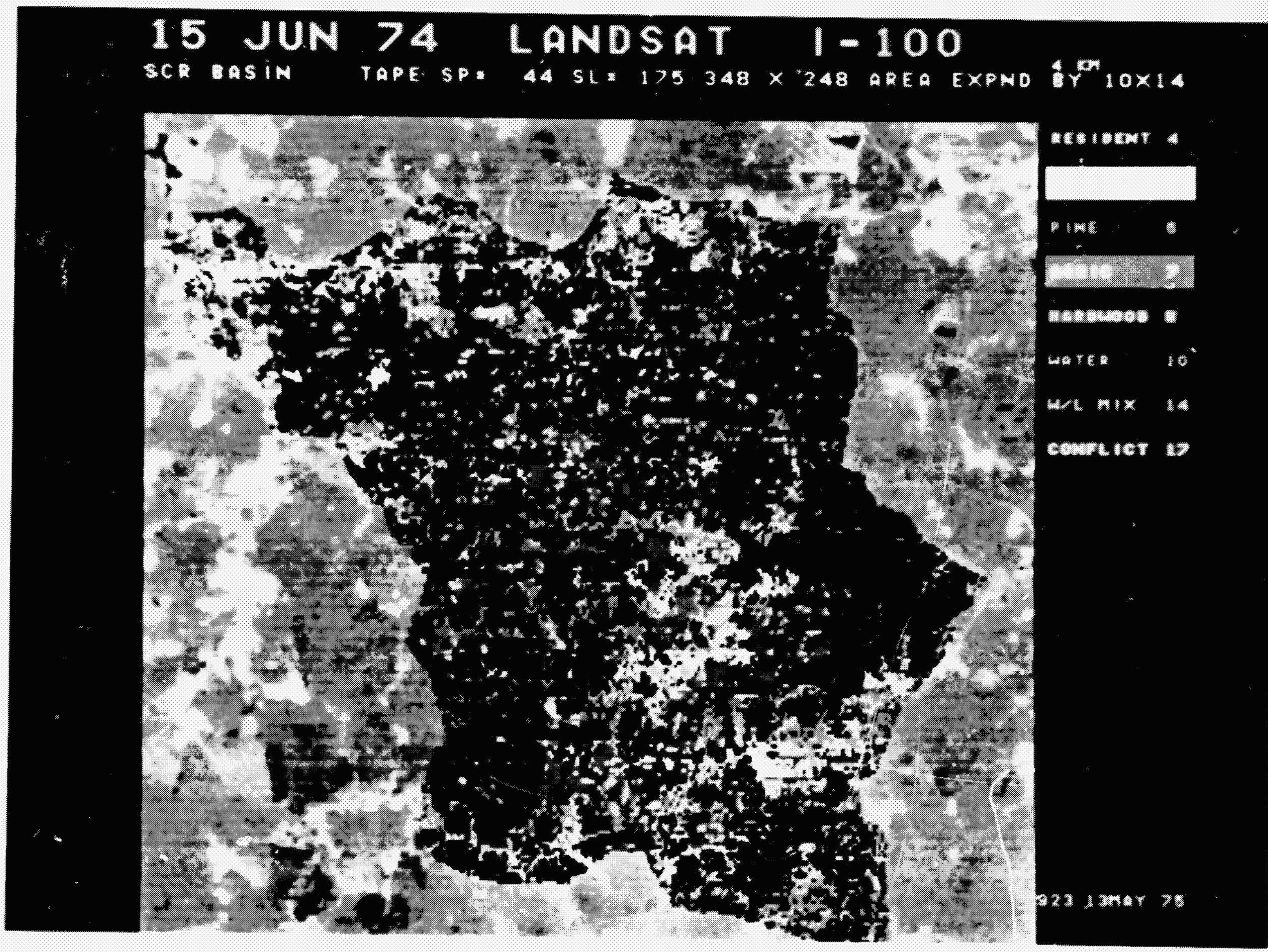


Figure 17.- Land cover classes from LANDSAT for Swift Creek Reservoir watershed on 15 June 74.

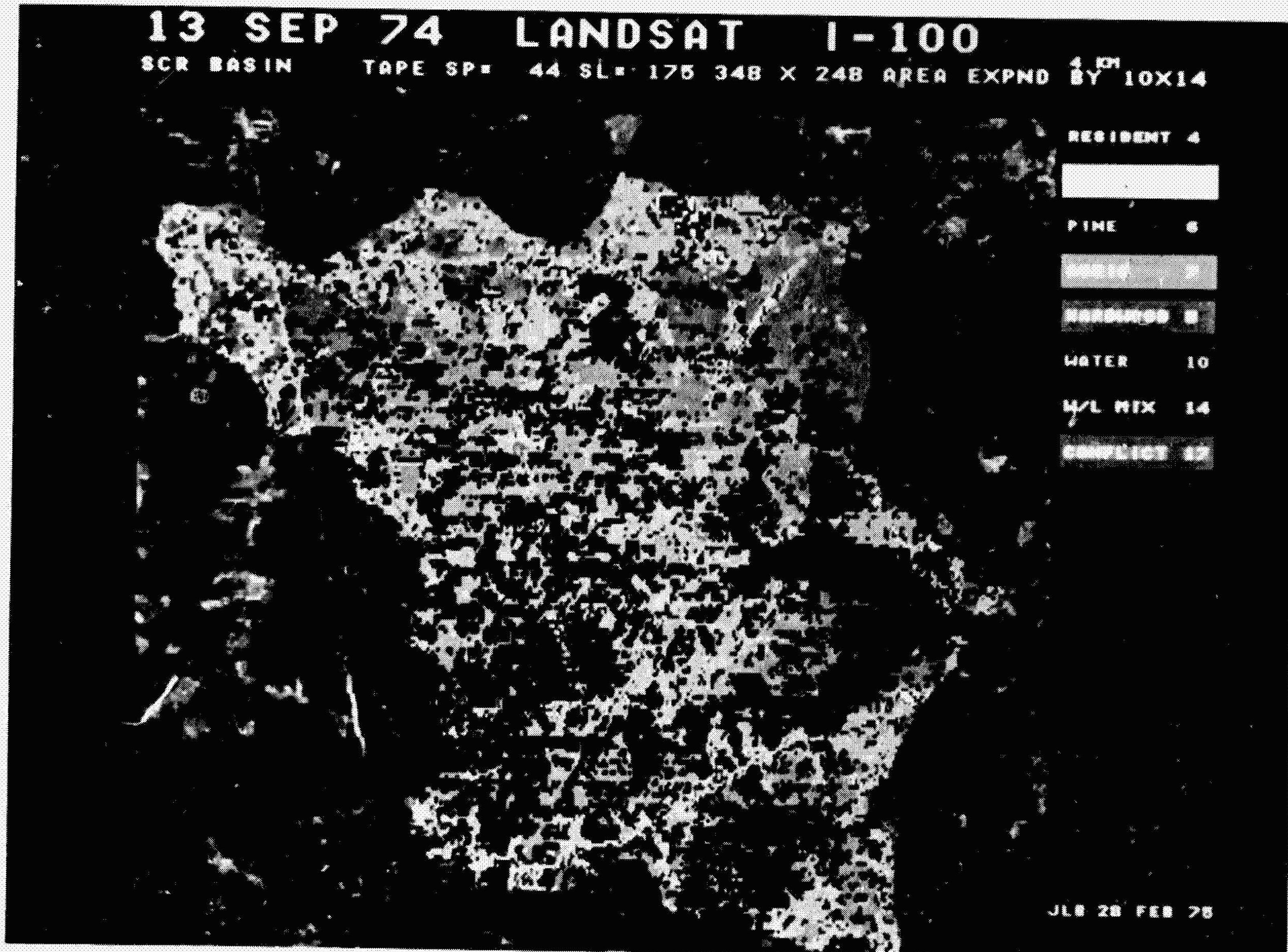


Figure 18.- Land cover classes from LANDSAT for Swift Creek Reservoir watershed on 13 Sept 74.

THE LANDSAT-1 MULTISPECTRAL SCANNER AS A TOOL IN THE CLASSIFICATION OF INLAND LAKES

E-11

By D. H. P. Boland, Eutrophication Survey Branch, U.S. Environmental Protection Agency, Corvallis, Oregon, and Richard J. Blackwell, Jet Propulsion Laboratory, Pasadena, California

N76-17495

ABSTRACT

This study has focused on relationships between LANDSAT-1 multispectral scanner (MSS) data and the trophic status of a group of lakes located in the north-northeastern part of the United States. MSS data were used to predict the magnitudes of two trophic state indicators, estimate lake position on a multivariate trophic scale, and automatically classify lakes according to their trophic state.

Initially, principal component ordination was employed to ascertain the trophic state of 100 lakes using the indicators: chlorophyll a, conductivity, inverse of Secchi transparency, total phosphorus, total organic nitrogen, and productivity as measured by a standard algal assay yield test. The resultant PC1 values are indicative of the lakes' positions on a multivariate trophic scale.

MSS data for some 20 lakes were extracted from computer-compatible tapes (CCT's) using a binary marking technique. Output was in the form of descriptive statistics and photographic concatenations. MSS color ratios were incorporated into regression models for the prediction of Secchi disc transparency, chlorophyll a, and lake position on the trophic scale. Lake trophic state-MSS relationships were also examined using three-dimensional color ratio models. Automatic image processing techniques were used in conjunction with MSS data and trophic state index values to classify each lake pixel-by-pixel. Classification products included both gray scale and color-coded photographic prints.

The study results indicate that the LANDSAT-1 system, although handicapped by both low spectral and spatial resolution as well as excessive cloud cover, can be used as a supplemental data source in lake survey programs. The sensor's usefulness is most apparent when the seasonal contrasts between lakes at different points on a trophic scale are at a maximum. The use of CCT's along with digital image processing techniques is essential if maximum benefits are to be derived from the sensor.

INTRODUCTION

The United States is estimated to have some 80,000-100,000 lakes. Rational management of the nation's lacustrine resource necessitates, as a first step, an assessment of each lake's trophic status. Data collection for the determination of trophic state is a costly, time-consuming process, especially when thousands of lakes are to be evaluated. The need exists to find a method of rapidly and economically assessing the trophic condition of our lakes.

Satellite-borne sensors, such as those found on the LAND SATELLITE-1 (LANDSAT-1), merit close scrutiny as tools with the potential to collect data relevant to lake monitoring and survey programs. They are endowed with a synoptic view, yield a time record, and expand the spectral limits of the human eye. The successful orbiting of LANDSAT-1 and LANDSAT-2 affords the opportunity to investigate the capabilities of one type of sensing system. This paper reports the progress of an on-going investigation which is examining relationships between multispectral scanner (MSS) data and the trophic state

of lakes in Minnesota, Wisconsin, Michigan, and New York[1] (Figure 1). More specifically, the MSS was scrutinized as to its capability for estimating lake area, predicting two trophic state indicators, and classifying lakes according to a ground truth-derived trophic scale. The project, a cooperative effort of the U.S. Environmental Protection Agency's (EPA) Pacific Northwest Environmental Research Laboratory and the National Aeronautics and Space Administration's (NASA) Jet Propulsion Laboratory (JPL), was initiated in early 1973.

BACKGROUND

Eutrophication Survey personnel at EPA's Pacific Northwest Environmental Research Laboratory visually examined lakes on MSS imagery received shortly after spacecraft launch. Tonal differences were noted and it was conjectured the differences might correlate with the trophic status of the lakes. While tonal variations were observed for lakes in many states (e.g., Florida, South Dakota, Minnesota), MSS Scene 1017-16093, recorded at an altitude of approximately 917 kilometers over southeastern Wisconsin and northeastern Illinois on 9 August 1972, will serve to illustrate this point.

Figure 2 is a reproduction of an EROS Data Center photograph of the scene as recorded in the near-infrared (IR2; 800 to 1,100 nanometers) spectral band. Water bodies, including the larger streams, stand out boldly against the lighter-toned land features. The labelled lakes, excluding Lake Michigan, were sampled by EPA's National Eutrophication Survey (NES) during the 1972 open-water season. Gray tone differences are not evident among the lakes, nor are tonal patterns visible on any of the lakes. IR2 is, however, a good spectral band for the location and demarcation of water bodies. Some caution is necessary when conducting a lake enumeration on the photograph because some of the "lakes" are in reality shadows cast by cumulus clouds.

Figure 3 is the same scene recorded in near-infrared (IR1; 700 to 800 nanometers). Tonal differences are apparent, at least on the original photographic print, among the lakes, and patterns are evident on some of the lakes (e.g., Lake Koshkonong). Lakes are readily located and their boundaries delimited in this band.

Figure 4 is a red light (RED; 600 to 700 nanometers) MSS photograph of the scene. Marked gray tone differences are apparent among the lakes. Lakes commonly recognized as eutrophic (e.g., Lake Como) tend to appear light in tone and meld in with the land features. Lakes with relatively good water quality are characterized by darker tones.

The green light (GRN; 500 to 600 nanometers) sensed by the MSS was used to produce the Figure 5 photograph. Although the lakes are difficult to discern, a result of low contrast among the scene elements, differences among the lakes can be detected with the unaided eye.

It is apparent from the visual examination of MSS scene 1017-16093 and additional scenes from several other states that the satellite-borne MSS is collecting data which may be of value in the classification and monitoring of lentic bodies. The examination results suggest that GRN, RED, and IR1 contain most of the information relating to the assessment of trophic status.

Lake Color

It is readily apparent, even to the casual observer, particularly if he or she is looking downward from an aircraft, that lakes differ in color. Many investigations have

1. The geographic scope has been expanded to include lakes sampled by EPA's National Eutrophication Survey in the Southeast (1973), West (1974), and Far West (1975).

been undertaken to develop a comprehension of the processes which result in the observed phenomena (ref. 1). Scherz, et al. (ref. 2) have investigated the total reflectance (surface reflectance plus volume reflectance) curves of pure water and natural waters under laboratory conditions using a spectrophotometer. They reported that the addition of dissolved oxygen, nitrogen gases, and salts (e.g., NaCl, Na_2SO_4) had no apparent effect on the reflection curve. However, water from lakes in the Madison (Wisconsin) area had reflectance curves that both differed from the distilled water curve and from each other (Figure 6). The lake water differences can be attributed to the presence of different algal organisms. Filtration of the lake waters produced similar reflectance curves.

The color of a lake is a function of the electromagnetic energy backscattered from the lake body to the sensor. Lake color ranges from the blue of pure water through greenish blue, bluish green, pure green, yellowish green, greenish yellow, yellow, yellow brown, and clear brown. Lake color need not be, and is usually not the same as, the color of lake water. Lakes which are blue in color lack appreciable quantities of humic materials and colored material in suspension (e.g., phytoplankton). Waters with high plankton content possess a characteristic yellow-green to yellow color.

Figure 7 depicts the spectral reflectance curve for chlorophyll-bearing plants (refs. 3, 4, 5). The reflectance of the chlorophyll-bearing plants varies greatly as illustrated. by the curve with an abrupt increase at about 700 nanometers. Although the water tends to attenuate the infrared energy in a relatively short distance, the magnitude of the plant reflectance in the near-infrared should make it possible to detect chlorophyll at or near the water surface. However, the chlorophyll signature may be masked by other materials, for example suspended sediments.

Peripheral Effects

The character of the electromagnetic energy received by the sensor, in this case the LANDSAT-1 MSS, has been shaped through interaction with numerous environmental phenomena. The degree of scattering and absorption imposed on the signal returned from water bodies is related to atmospheric transmittance and can result in changes in lake color when sensed at aircraft and satellite altitudes (ref. 6, 7). The magnitude of the adverse atmospheric effects can be reduced, though not completely eliminated, by using MSS data collected on clear days with little cloud cover. The use of MSS color ratios in lieu of raw data values may be of value in reducing the magnitude of solar angle induced effects and atmospheric effects.

Most of the electromagnetic energy entering a lake is attenuated through the process of absorption. Although only a small percentage of the incident energy is backscattered from the lake water volume, it is the focus of interest in remote sensing of water quality. Its spectral characteristics have been shaped by the materials found in the lake water (e.g., dissolved and suspended materials, plankton, aquatic macrophytes). Lake bottom characteristics will also affect the intensity and/or the spectrum of the volume reflectance in settings where water transparency permits the reflection of a significant amount of energy from the bottom materials. In studies involving the estimation of water depth or the mapping of bottom features, it is essential that the lake bottom be "seen" by the sensor. Bottom effects are capitalized upon and put to a beneficial use. However, in this investigation bottom effects are considered to be an undesirable peripheral effect. A sensor with the capabilities of the MSS in not able to "see" much deeper into a lake than secchi disc transparency depth. The Secchi transparencies of the NES-sampled lakes were, in most cases, relatively small when compared to the mean depth of each respective lake. The assumption was made that bottom effect was relatively insignificant when considering each of the selected lakes as an entity.

Absolute quantification of remotely sensed phenomena requires that all of the effects be accounted for in the return signal. Although the approach used here to reduce the magnitude of the undesirable peripheral effects might be criticized as simplistic or naive, it does serve as a starting point in the investigation of lake color-trophic state relationships using satellite-borne sensors.

METHODS

Lake Ordination Using Principal Component Analysis

One hundred lakes sampled during the 1972 open-water season by EPA's National Eutrophication Survey were selected for the development of a multivariate trophic state index (ref. 8). A careful examination of the physical, chemical, and biological parameters measured by NES helicoptor-borne scientists resulted in the selection of six trophic indicators for incorporation into the index, namely: chlorophyll a, (CHLA), conductivity (COND), total phosphorus (TPHOS), total organic nitrogen (TON), Secchi disc transparency (SECCHI), and productivity as measured by a standardized algal assay test (AAY). The inverse of Secchi disc transparency (ISEC) was employed so that all of the indicators would increase as trophic status increases. The six indicators were selected because they are quantitative, considered to be important measures of trophic state and satisfy Hooper's (ref. 9) criteria. Annual mean values for CHLA, TPHOS, ISEC, and COND were used in the analysis. AAY and TON measurements were limited to the fall overturn sample, precluding the use of an annual mean.

Principal components analysis may be used to reduce the dimensionality of a multivariate system by representing the original attributes as functions of a smaller number of uncorrelated variates which are linear functions of the attributes. The objective is to summarize most of the variance in the system with a lesser number of "artificial" variates (i.e., principal components). The data for each of the trophic indicators were transformed with natural logarithms and further standardized to zero mean and unit variance. Following the development of the normalized eigenvectors and eigenvalues, the first principal component was evaluated for each of the 100 lakes under study.

Extraction of Lake Data from Computer-Compatible Tapes

Transparencies and CCT's for 12 different dates of MSS coverage were processed to extract pertinent lake data. Data extracted from transparencies using a microdensitometer contained a lot of "noise" and the approach, although initially attractive, was dropped in favor of using the CCT's. The processing of the CCT's was accomplished at JPL's Image Processing Laboratory (ref. 10, 11).

Processing commenced with a change of tape format and expansion of the data to 8-bits of precision giving 256 (0-255) digital number (DN) levels. Previous testing indicated that the LANDSAT-1 IR2 band gives a good indication of surface water extent. Water-related intensity values fall toward the lower end of the DN range. A binary mask was created from the IR2 data by setting all DN values at or below a specific numerical value to a value of 1, and setting all other values to 0. The IR2 DN level of 28 was selected as the upper limit for water-related features.

The binary mask was upgraded by eliminating all of the lakes, ponds, streams, and any wetland features which may be present, leaving just the lake of interest. After an examination of a test multiplication, each spatially equivalent picture element (pixel) within each MSS band (GRN, RED, IR1, IR2) was multiplied by the mask, thereby extracting the subject lake from its terrestrial matrix. Descriptive statistics were then generated

(*e.g.*, number of pixels, mean DN for each band). Lake area was determined from pixel counts using the conversion factor: 1 pixel = 0.47 hectares.

Estimation of Trophic Indicators and Trophic State

Ideally, the estimation of the magnitude of trophic state indicators should be done using concurrent data to derive the maximum benefit. However, in this investigation, it was necessary to use what may be termed "near-concurrent" ground truth which was collected several days before or after the time of satellite overflight. Nevertheless, models developed from such a temporal arrangement are of some value in demonstrating general trends existing between MSS data and ground truth.

Although attempts were made to estimate trophic indicators for other dates of MSS coverage, for purposes of this paper, attention will focus on MSS Scenes 1017-16091 and 1017-16093 recorded over eastern Wisconsin on 9 August 1972. These scenes were selected on the basis of temporal proximity to NES ground truth sampling dates, the high quality of the MSS data, and the presence of a relatively large number of NES-sampled lakes (N = 20).

The areal and spectral resolution of the LANDSAT-1 MSS should permit the detection of phenomena related to eutrophication; for example, Secchi disc transparency and chlorophyll *a*. Initially, an R-mode Pearson product-moment correlation analysis was made using MSS data, including MSS ratios, and the recorded Secchi disc and chlorophyll *a* values for the 20 lakes (Table I). Several multiple regression models were developed to predict each of the indicators using MSS colors and color ratios. The use of color ratios as independent variables had appeal because this approach normalizes the MSS data by removing the brightness components.

While the estimation of specific trophic indicators is of value in studies of lake water quality, the question arises, "Can a lake's position on a trophic scale be predicted using MSS data?" With this in mind, MSS coverage of the 20 lakes for three dates (9 August 1972, 11 June 1973, 17 July 1973) were examined for correlation with the trophic state index (PC1) values of the lakes (Table II). Multiple regression was then used to predict lake position on the scale using MSS color ratios as the independent variables.

A less rigorous approach to the study of PC1-MSS relationships was undertaken using three-dimensional plots of the MSS color ratios GRNIR1, GRNRED, and REDIR1.

Multispectral Classification of Lakes Using Digital Processing Techniques

Lake classification using the 9 August 1972 MSS data and the trophic state index (PC1) values of the 20 NES lakes was attempted using the maximum likelihood algorithm. The classification was conducted using the spectral bands GRN, RED, and IR1; the IR2 band was not utilized since it resulted in little or no spectral separation of classes. The number of spectral classes was set by establishing one class for each different PC1 value among the 20 Wisconsin lakes. This resulted in 19 different classes (Table III). Butte des Morts and Nagawicka have the same PC1 value and were assigned to the same class. Statistical samples were obtained for each lake as belonging to a particular class. For example, the computer was trained to perceive Beaver Dam Lake as belonging to Class 19. Each pixel in the 20 lakes was then classified by the computer into one of the 19 classes. The classification results were put out in the form of descriptive statistics and both black and white and color-coded photographs.

RESULTS AND DISCUSSION

Lake Area Estimation

The surface areas of the 20 Wisconsin lakes for 9 August 1972 (Scenes 1017-16091 and 1017-16093) are generally within 10% of values derived from U.S.G.S. topographic sheets. Adding the 20 lake map-derived area estimates and then comparing the resultant value with the composite value derived from MSS data resulted in a ratio of 1.016:1.000. A visual examination of area ratio for lakes in other MSS scenes indicated that the MSS can give adequate estimates of lake surface area when a DN value of 28 is used as the "cutoff" point for extracting lakes from their terrestrial matrix. The area estimation capabilities of the MSS are of value, not only in the study of lakes with known area but also in geographic regions for which there is no accurate topographic or photographic coverage.

Trophic Indicators and Trophic State

Efforts to use 9 August 1972 MSS color ratios for the prediction of mean Secchi disc transparency resulted in a multiple regression model which explains about 87 percent of the variance about the mean (ref. 1). Although the number of observations (N = 20) is rather small, the results suggest that the MSS scanner can be used to predict Secchi transparency.

The attempt to predict mean chlorophyll _a_ levels in the same lakes resulted in a model which explains about 83 percent of the variance about the mean. The model does a fair job of estimating mean chlorophyll _a_ levels in the 20 lakes. Large residuals are evident, primarily in the cases of lakes which have very poor water quality.

Regression models were also developed to predict the trophic state of the 20 Wisconsin lakes for three dates of MSS coverage (9 August 1972, 11 June 1973, 17 July 1973). The coefficients of multiple determination ($R^2 \times 100$) are respectively 81 percent, 70 percent, and 81 percent. Efforts to develop a single model which could be used to estimate trophic state for each of the MSS sampling dates drew negative results. Indeed, the use of regression techniques for the 12 different dates of MSS coverage resulted in 12 different models for the prediction of trophic state. Models constructed using MSS data collected early in the open-water season were generally inadequate.

A less sophisticated but practical approach to evaluating relationships between MSS data and trophic state involves the visual examination of MSS data in light of a general knowledge of the lakes as well as their trophic state index values (PC1). Although this could be done through the use of matrices, the use of a three-dimensional color ratio model was favored because it is very conducive to pattern detection and interpretation.

The color ratio model for 9 August 1972 is found in Figure 8. The numerals inside a "ball" are the lake's serial number and those near the lake's name represent its PC1 value. There is a very definite trend for the color ratios to increase as one moves from lakes considered to be located near the eutrophic end of the scale (_e.g._, Beaver Dam) toward those situated more closely toward the oligotrophic end (_e.g._, Green)[2]. It

2. The mean IR1 DN level for several hypereutrophic lakes located in Minnesota actually exceeded their mean RED DN levels, effectively isolating them from other NES-sampled lakes in the color ratio model (Figure 9).

is unrealistic to expect complete agreement between the position of the lakes in the color ratio model and their respective PC1 values. However, assuming that the PC1 value of Middle Lake is representative of its trophic state, it is "out of place" relative to the other lakes. Its color ratio coordinates are indicative of a lake situated more closely toward the eutrophic end of the trophic scale. Several factors may be responsible for this apparent misclassification. The sensor may very well be "seeing" large masses of aquatic macrophytes and/or the lake bottom. Middle Lake is known to have macrophyte problems and extensive shallows.

The 11 June 1973 model at the same 20 lakes is shown in Figure 10 along with three other lakes. Many of the lakes have shifted their position significantly. The color ratio-trophic state index relationships so evident in the 9 August 1972 model are not as obvious.

Figure 11 depicts the Wisconsin lakes in a model constructed from 17 July 1973 color ratios. Although not identical in all respects, the model bears a marked resemblance to the 9 August 1972 model.

An examination of both the three-dimensional color ratio models and their associated regression models for the 12 dates of coverage suggested that the utility of the MSS for the estimation of trophic state is dependent to a substantial degree upon the time of the year. MSS data recorded early in the open-water season correlate poorly with lake PC1 values; the correlations are better in the case of MSS data recorded later in the growing season.

Multispectral-Trophic Classification

Many of the data processing systems which automatically classify LANDSAT-1 MSS-sensed phenomena can output the reduced data in the form of both descriptive statistics and some sort of imagery. If the classificatory statistics would indicate that each lake is homogenous, the analysis could stop at this point. However, it is unlikely to find a lake that has the same trophic characteristics throughout its areal extent. The question arises, "What trophic-related patterns exist in each lake?" This necessitates the development of some sort of imagery.

Images of the machine-classified lakes can be produced in the form of line printer copy using different symbols to represent the various trophic classes and also as photographic products. The photographic approach is attractive because they are compact, easily handled, have much greater resolution than line printer copy of equal size, and are readily interpretable, particularly when in color.

The multispectral classification results for the 20 Wisconsin lakes (9 August 1972) are displayed as a color-coded concatenation (Figure 12). Class 1 pixels, represented by black, are located toward the eutrophic end of the trophic scale and Class 19 pixels (dark blue) toward the oligotrophic end. It would be incorrect to call a Class 19 pixel or lake oligotrophic because none of the Wisconsin lakes meet the criteria normally attributed to oligotrophic lakes. The pronounced linear features in Figure 12 are an artifact introduced by a defect in the MSS.

Differences among and within the lakes are readily apparent. Some of the lakes (e.g., Kegonsa and Beaver Dam) present a relatively homogenous appearance. Others (e.g., Winnebago and Poygan) exhibit a diversity of trophic classes. Some of the lakes have features which bear mentioning.

The appendix-like structure which appears attached to the northeast quadrant of Delavan Lake is the entry point of Jackson Creek, the lake's major tributary. Its waters,

known to be nutrient rich through contributions from sewage treatment plants and agricultural drainage, have been placed in Class 1.

In this study, Lake Tichigan has been defined to include the lake proper and what is commonly referred to as the "widening" in the Fox River. The lake proper has been assigned to Class 5 and the "widening" to several classes including 1, 2, and 4. Ground truth measurements indicate that the "widening" has a smaller Secchi disc transparency and a substantially higher chlorophyll a level than the lake proper.

The Class 1 water found along the northern shore of Lake Pewaukee may be related to the presence of algae and macrophytes. The helicopter-borne survey teams reported algal scum covering the surface of the northern portion of the lake. Heavy growths of emergents covered the lake shallows.

The appendix-like portion of Green Lake, located at its northeast end, is the area into which Silver Creek flows. The area receives a substantial nutrient load from a sewage treatment plant and the surrounding agricultural lands. Its pixels have been classified as belonging to Class 1 and Class 2.

White areas within the lake images are indicative of either clouds or land-related phenomena. The white area in the northeastern portion of Lake Winnebago represents cloud cover. The north-south oriented linear feature located in the eastern end of Lake Butte des Morts is a roadway.

Complete accord does not exist between the trophic index values of the 20 lakes and the results of the multispectral classification. The disparity is very evident in the cases of Lakes Nagawicka, Koshkonong, and Oconomowoc where few, if any, pixels were found that fell into the class for which the lake served as a training area. This is not surprising because there was an indication in the three-dimensional color ratio model and the PC1 regression model for 9 August 1972 that a disparity existed between some of the lake PC1 values and their MSS data.

An examination of the 9 August 1973 MSS descriptive statistics for the 20 lakes indicated that the use of fewer trophic classes would yield a classification product more in tune with reality. The computer was retrained as indicated in Table III and the lakes were then reclassified. The revised classification, consisting of 11 classes (Figure 13), may be more representative of lacustrine trophic state than the 19-class scheme.

CONCLUSIONS

The LANDSAT-1 multispectral scanner is collecting data which can be incorporated into lake monitoring and survey programs. The interim results reported here suggest that MSS color ratios can be used to predict the magnitude of selected trophic state indicators and a multivariate trophic state index. However, the accuracy of the predictions varies considerably from date to date. The development of a trophic state classification employing computer-generated color-coded photographs should aid investigators in classifying large numbers of lakes both rapidly and economically. The use of CCT's along with digital image processing techniques is essential if maximum benefits are to be derived from the sensor.

It appears that the LANDSAT-1 MSS has the capability of providing supplemental data relating to water quality in inland lakes. Further refinement both in the sensor and the data processing techniques should make multispectral imagery collected from space platforms a valued tool in lake survey and monitoring activities.

ACKNOWLEDGMENTS

This paper represents the results of one phase of the research carried out at the Pacific Northwest Environmental Research Laboratory, U.S. Environmental Protection Agency, under JPL Contract EZ-608770 and at the Jet Propulsion Laboratory, California Institute of Technology, under NASA contract number NAS7-100.

REFERENCES

1. Boland, D. H. P. 1975. An evaluation of the Earth Resources Technology Satellite (ERTS-1) Multispectral Scanner as a Tool for the Determination of Lacustrine Trophic State. Ph.D. Thesis. Oregon State University: Corvallis. 311 pp

2. Scherz, J. P., D. R. Graff, and W. C. Boyle. 1969. Photographic characteristics of water pollution. Photogrammetric Engineering. 35:38-43.

3. Bressette, W. E., and D. E. Lear, Jr. 1973. The use of near-infrared reflected sunlight for biodegradable pollution monitoring. In: Proceedings Second Conference on Enviromental Quality Sensors. 10-11 October 1973. EPA National Environmental Research Center: Las Vegas. Session II: 70-89.

4. Spiess, F. N. 1970. Oceanic environment. In: Hydronautics. Edited by: H.E. Sheets and V. T. Boatwright, Jr. New York: Academic Press.

5. Katzoff, S. 1962. The electromagnetic-radiation environment of a satellite. Part 1. Range of thermal to X-radiation. NASA TN D-1360. N6? 15249. 75 pp.

6. Piech, K. R., and J. E. Walker. 1971. Aerial color analyses of water quality. Journal Survey Mapping Division. Proceedings American Society Civil Engineers. SU2 (8507) 8185-197.

7. Rogers, R. H., and K. Peacock. 1973. A techinque for correcting ERTS data for solar and atmospheric effects. In: Symposium on Significant Results obtained from the Earth Resources Technology Satellite-1. 5-9 March 1973. NASA (Goddard Space Flight Center). I (B): 1115-112?.

8. National Eutrophication Survey. 1974. National Eutrophication Survey methods for lakes sampled in 1972. U.S. Environmental Protection Agency National Eutrophication Survey Working Paper Number 1. PNERL (NERC-Corvallis) and NERC-Las Vegas. 40 pp.

9. Hooper, F. F. 1969. Eutrophication indices and their relation to other indices of ecosystem change. In: Eutrophication: Causes, Consequences, Correctives. Proceedings of a Symposium. 11-15 June 1967. Madison: University of Wisconsin. Washington, D.C.: National Academy of Science. pp. 225-235.

10. Blackwell, R. J., and D. H. P. Boland. 1974. Computer analysis of lakes from ERTS imagery. In: Northwest '74 Pacific Regional Symposium on Computing in the Resource Industry. Canadian Information Processing Society. 23-24 May 1974. Vancouver, B.C. pp. 147-157.

11. ____________. 1975. The trophic classification of lakes using ERTS multispectral scanner data. Proceedings American Society of Photogrammetry 41st Annual Meeting. 9-14 March 1975. Washington, D.C. pp. 393-414.

TABLE I CORRELATIONS BETWEEN GROUND TRUTH AND LANDSAT-1 MSS DATA (COLORS AND COLOR RATIOS) FOR 20 LAKES IN SCENES 1017-16091 and 16093

MSS COLORS AND RATIOS	PC1	CHLA	LNCHLA	SECCHI	LNSECCHI
GRN	0.518	0.812	0.718	-0.623	-0.662
RED	0.722	0.888	0.860	-0.788	-0.857
IR1	0.807	0.899	0.886	-0.741	-0.866
IR2	0.589	0.680	0.696	-0.492	-0.542
GRNRED	-0.823	-0.821	-0.886	0.865	0.919
GRNIR1	-0.806	-0.777	-0.838	0.685	0.803
GRNIR2	-0.470	-0.422	-0.521	0.357	0.476
REDIR1	-0.544	-0.476	-0.505	0.274	0.430
REDIR2	-0.026	0.028	-0.017	-0.156	-0.042
IR1IR2	0.516	0.522	0.474	-0.527	-0.507

TABLE II CORRELATIONS BETWEEN LANDSAT-1 MSS DATA (COLORS AND COLOR RATIOS) COLLECTED ON THREE DATES AND THE TROPHIC STATUS OF 20 WISCONSIN LAKES

MSS COLORS AND RATIOS	DATE OF LANDSAT-1 FLYOVER		
	9 AUGUST 1972	11 JUNE 1973	17 July 1973
GRN	0.518	0.151	0.479
RED	0.722	0.533	0.721
IR1	0.807	0.512	0.836
IR2	0.589	0.174	0.628
GRNRED	-0.823	-0.712	-0.749
GRNIR1	-0.806	-0.540	-0.820
GRNIR2	-0.470	-0.091	-0.485
REDIR1	-0.544	0.084	-0.422
REDIR2	-0.026	0.298	0.109
IR1IR2	0.516	0.445	0.479

TABLE III LAKE TROPHIC STATE INDEX CLASS ASSIGNMENTS FOR THE MULTISPECTRAL CLASSIFICATION TECHNIQUE

LAKE NAME	SERIAL NUMBER	PCI VALUE	COMPUTER TRAINED TO RECOGNIZE AS CLASS:	COMPUTER RETRAINED TO RECOGNIZE AS CLASS:
Beaver Dam	53	3.29	1	1
Tichigan	63	3.11	2	2
Koshkonong	56	2.45	3	5
Winnebago	49	2.36	4	3
Delavan	66	2.03	5	4
Poygan	47	1.68	6	5
Kegonsa	54	1.48	7	5
Butte des Morts	48	1.27	8	2
Nagawicka	61	1.27	8	9
Como	67	1.15	9	5
Pewaukee	62	0.59	10	6
Okauchee	59	-0.62	11	7
Pine	60	-0.71	12	8
Browns	64	-1.07	13	6
Rock	55	-1.21	14	10
Lac la Belle	57	-1.43	15	9
Green	51	-1.67	16	10
Geneva	68	-1.71	17	11
Oconomowoc	58	-1.82	18	10
Middle	65	-2.29	19	8

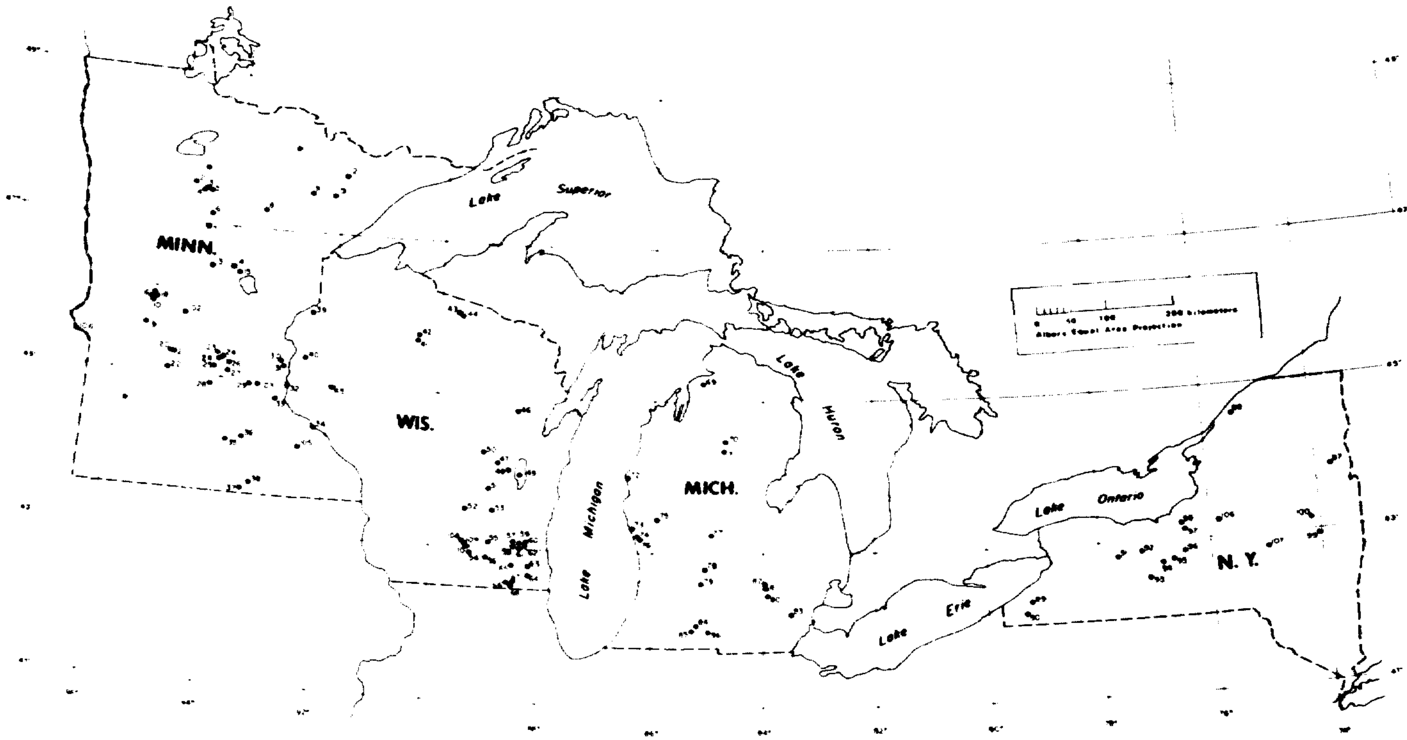


Figure 1. Location of the study lakes. The lakes with serial numbers 1-100 were used in the principal component ordination analysis. The lakes in east-southeastern Wisconsin serve as a focus for this paper.

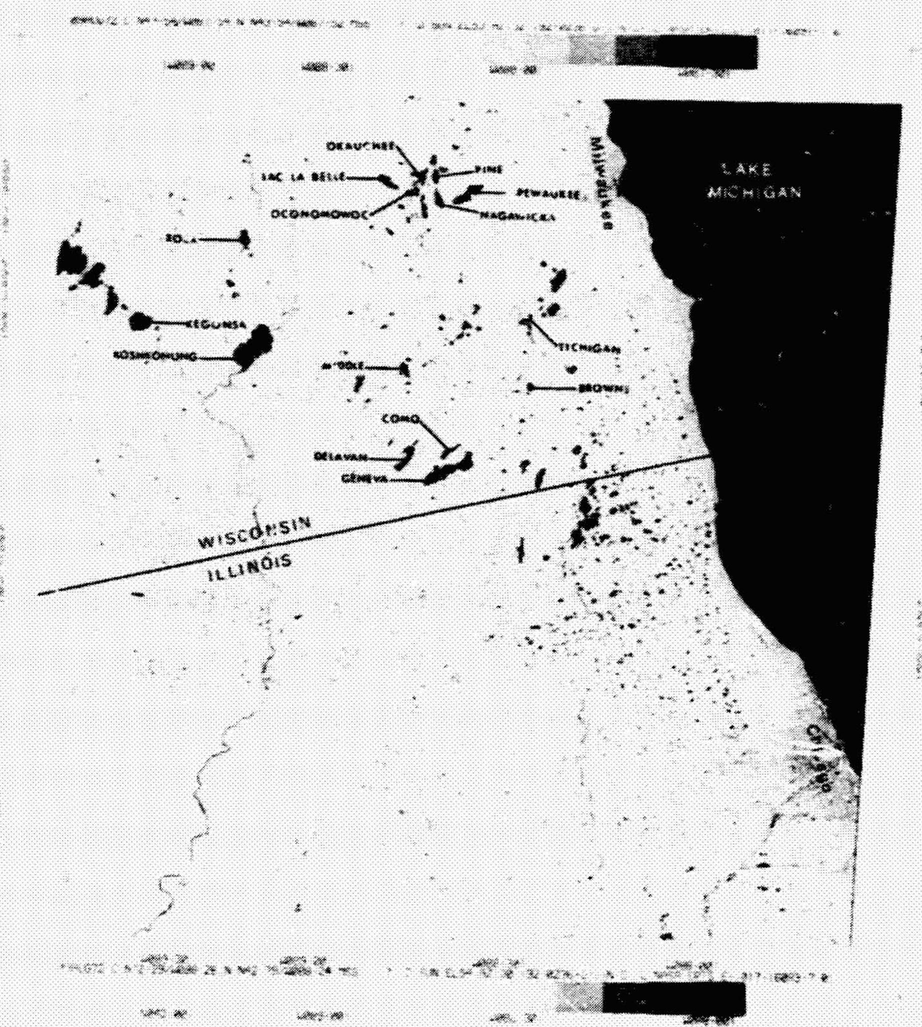


Figure 2. Reproduction of an EROS Data Center IR2 print of Scene 1017-16093 (9 August 1972). Water bodies stand out in stark contrast to the lighter-toned land features. The labelled lakes, excluding Lake Michigan, were sampled by the National Eutrophication Survey during 1972. The photograph covers a distance of approximately 185 kilometers along each edge.

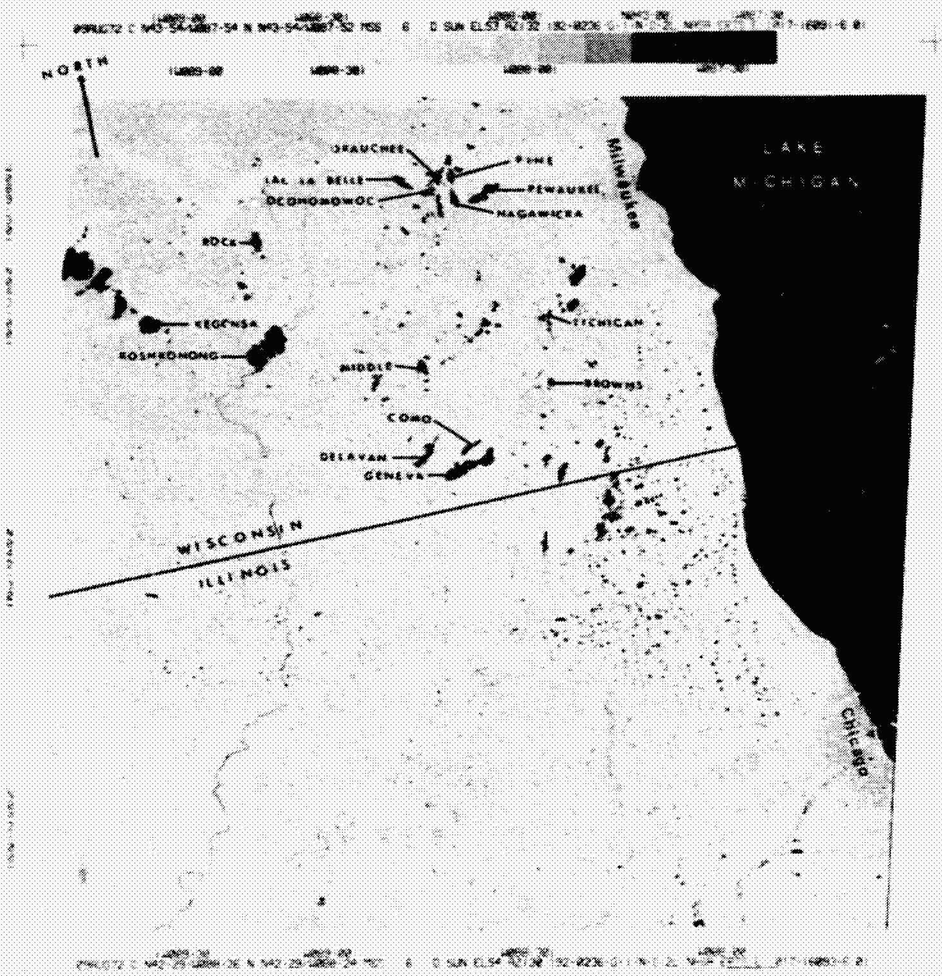


Figure 3. Reproduction of EROS IR1 print of Scene 1017-16093 (9 August 1972). Surface patterns are evident on some of the lakes (e.g., Lake Koshkonong). Each edge of the picture is equivalent to a ground distance of approximately 185 kilometers.

Figure 4. Reproduction of EROS RED (MSS Band 5) print of Scene 1017-16093 (9 August 1972). Variations in gray tone are readily apparent among the lakes and suggest differences in water quality. Lake Geneva, characterized by relatively high water quality, is dark in tone compared with, for example, eutrophic Lake Koshkonong. The small ball-like white objects between Milwaukee and Chicago are cumulus clouds. Each edge of the picture is equivalent to a ground distance of approximately 185 kilometers.

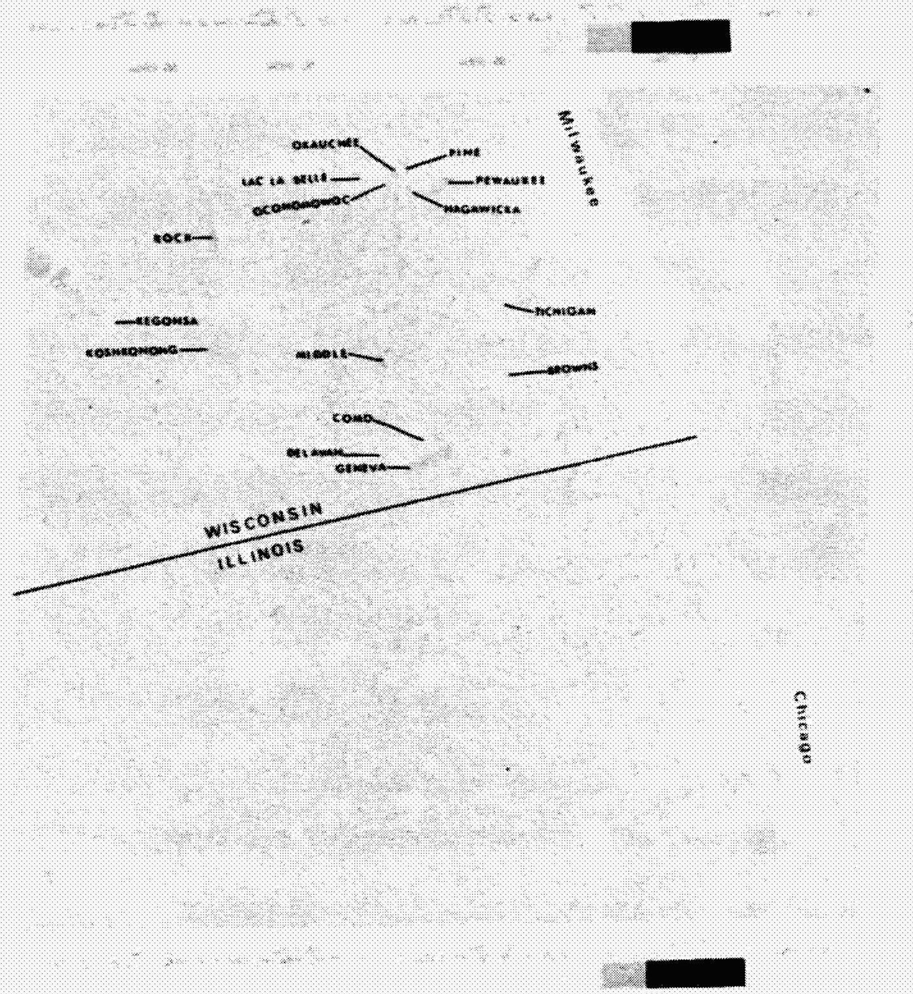


Figure 5. Reproduction of EROS GRN (MSS Bard 4) print of Scene 1017-16093 (9 August 1972). Scenes recorded in the green band generally lack contrast, but contain information useful in monitoring earth resources.

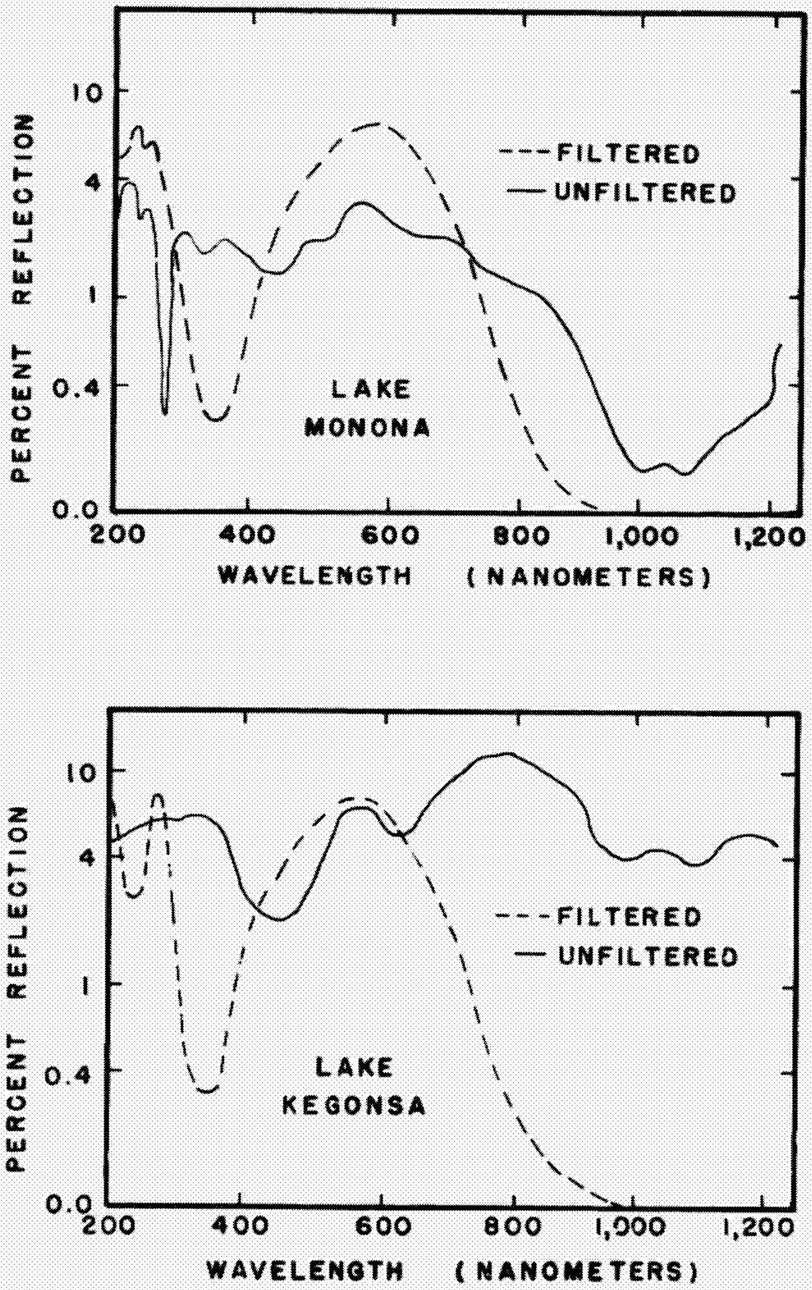


Figure 6. Reflection characteristics of filtered and unfiltered water samples from two Wisconsin lakes in the area of Madison. Adapted from Scherz, et al. (ref. 2).

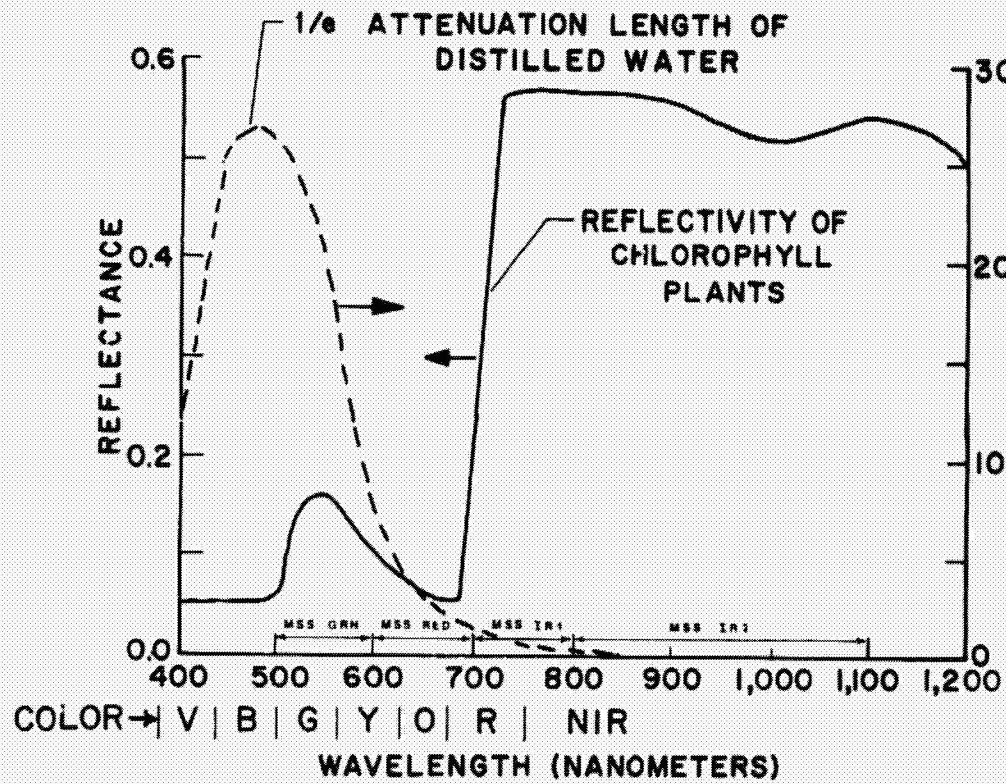


Figure 7. Comparison of the reflectance of chlorophyll-containing plants with the attenuation length of sunlight in distilled water. From Bressette and Lear (ref. 5). The attenuation curve is based on Spiess (ref. 6) and the plant reflectivity curve on Katzoff (ref. 7).

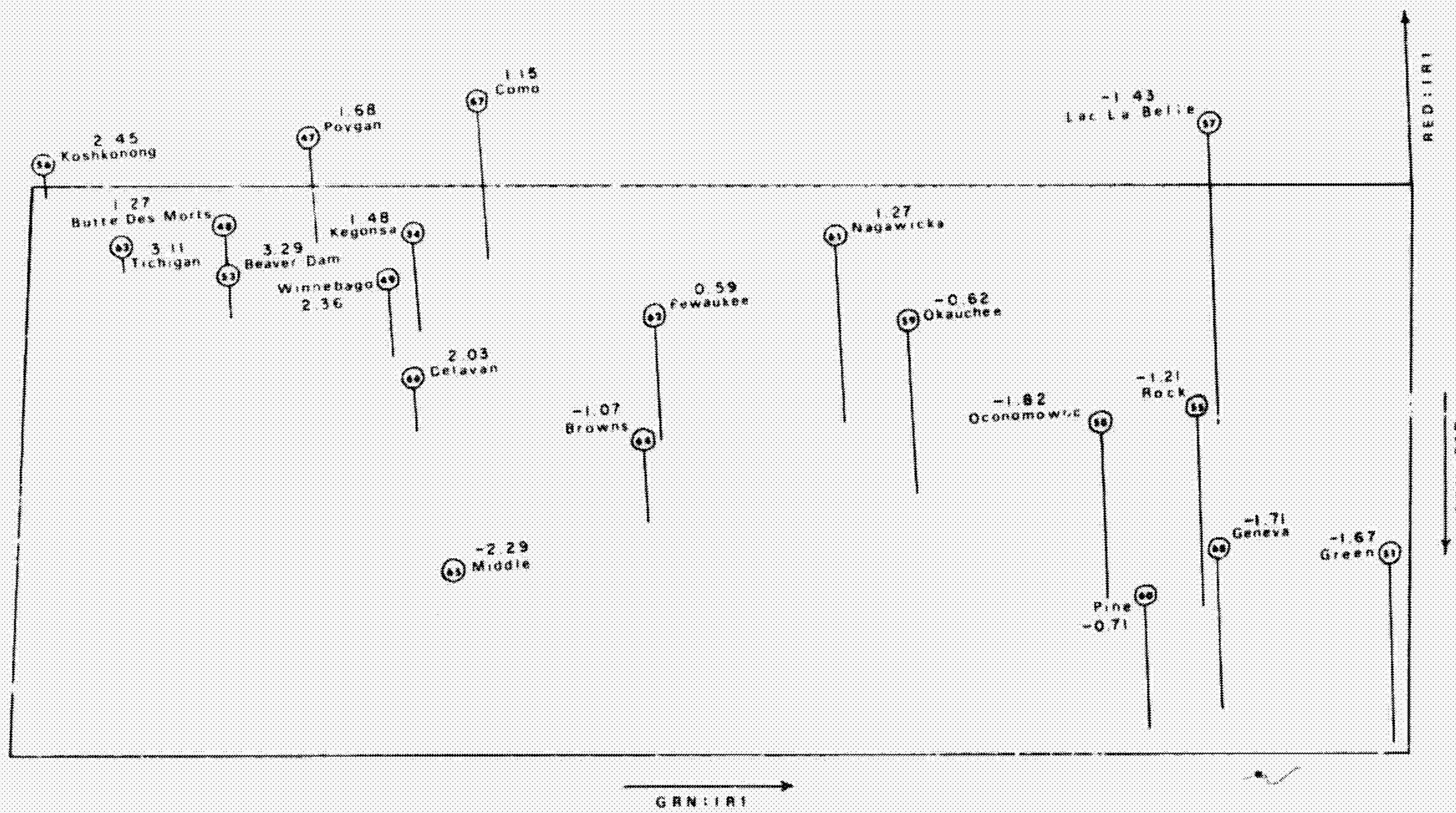


Figure 8. Three-dimensional color ratio model for 9 August 1972. The 20 Wisconsin lakes were extracted from LANDSAT-1 MSS Scenes 1017-16093 and 1017-16091. The scenes are in juxtaposition on the same flight line. The numerals inside the "balls" are lake serial numbers. The numerals near the lake names represent lake position on a trophic scale. Water quality decreases as the trophic index increases in magnitude.

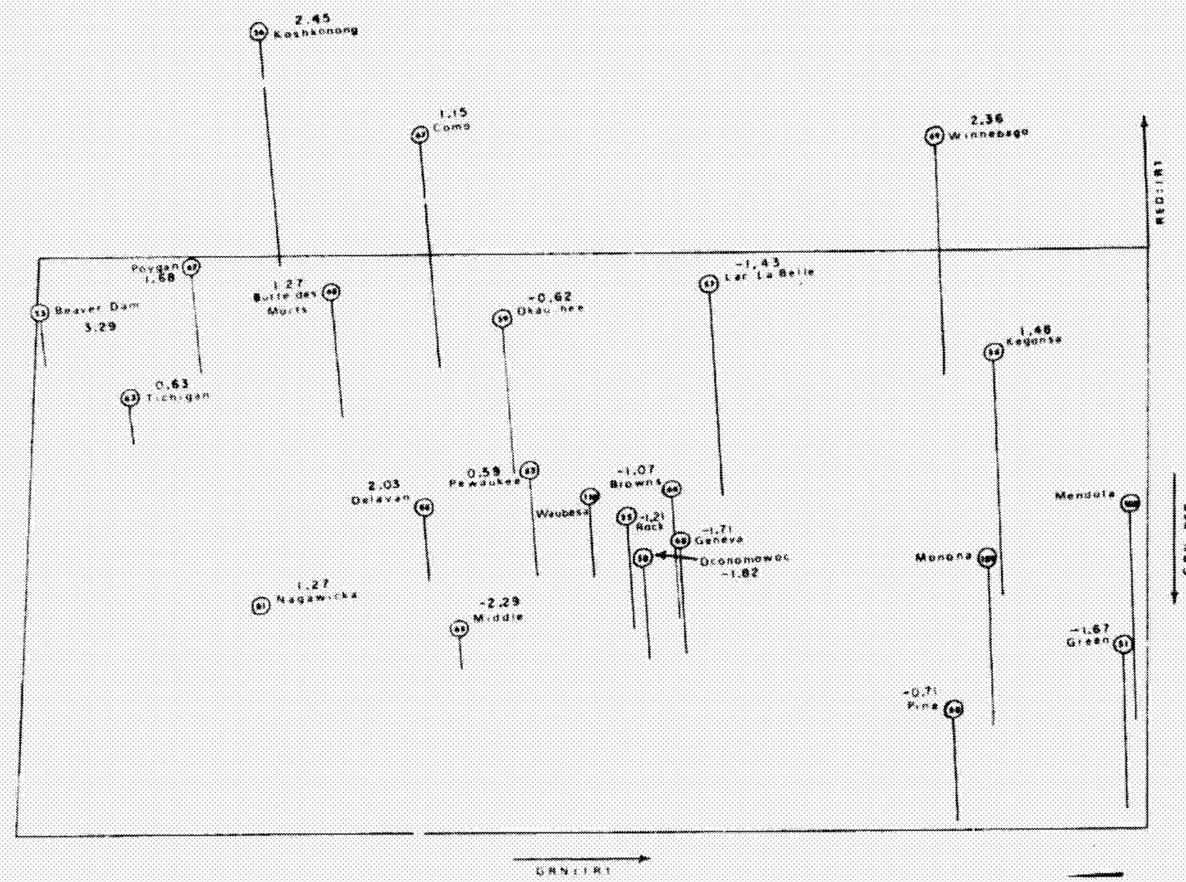


Figure 9. Three-dimensional MSS color ratio model of 8 Minnesota lakes extracted from LANDSAT-1 MSS Scene 1346-16381 (4 July 1973).

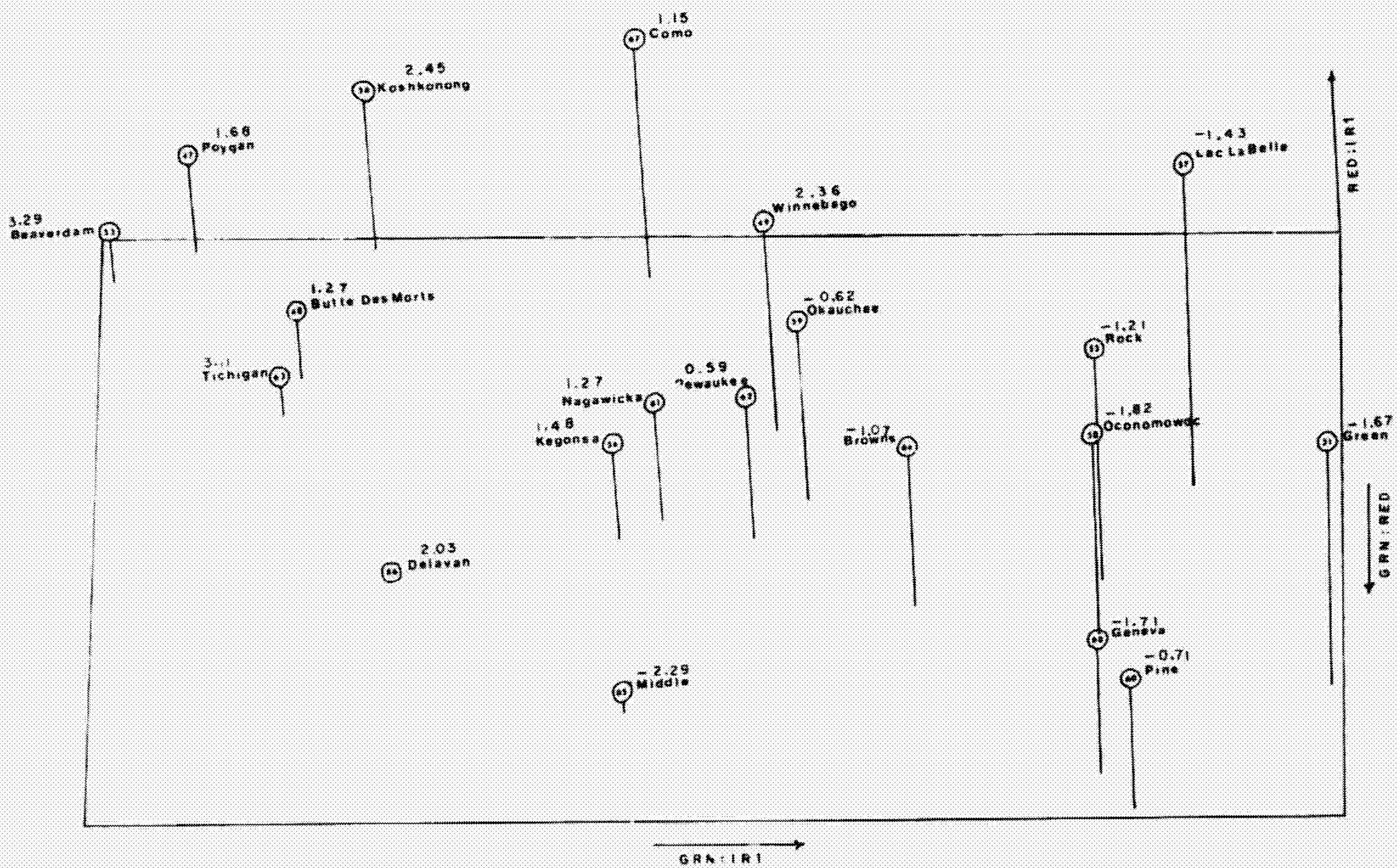


Figure 10. Three-dimensional color ratio model for 11 June 1973. The 23 Wisconsin lakes were extracted from LANDSAT-1 MSS Scene 1323-16100. Three of the lakes (Mendota, Monona, and Waubesa) fall outside the scope of the investigation, but are included because they are well-known by lake scientists.

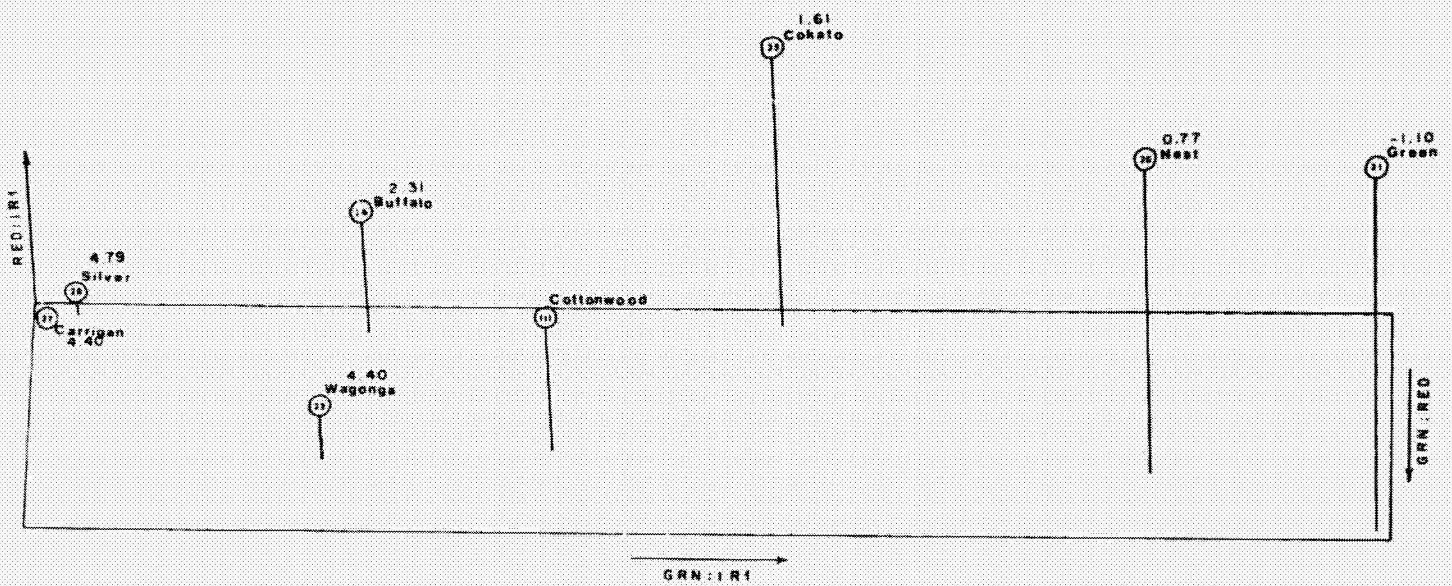


Figure 11. Three-dimensional color ratio model for 17 July 1973. The 20 Wisconsin lakes were extracted from LANDSAT-1 MSS Scenes 1359-16091 and 1359-16094.

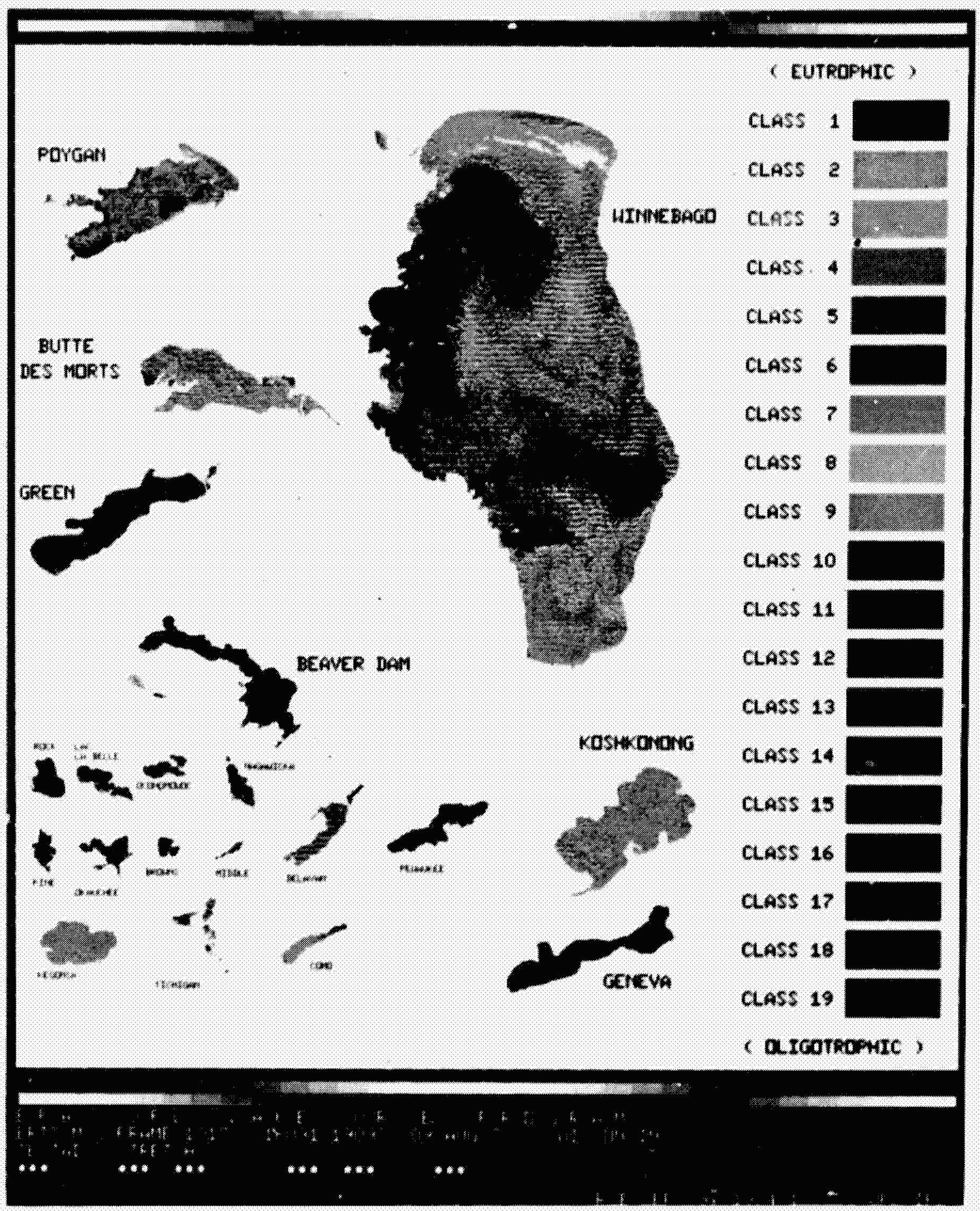


Figure 12. A color-coded concatenation of the 19-class classification of 20 Wisconsin lakes (9 August 1972). The scale labels merely indicate direction on the trophic scale.

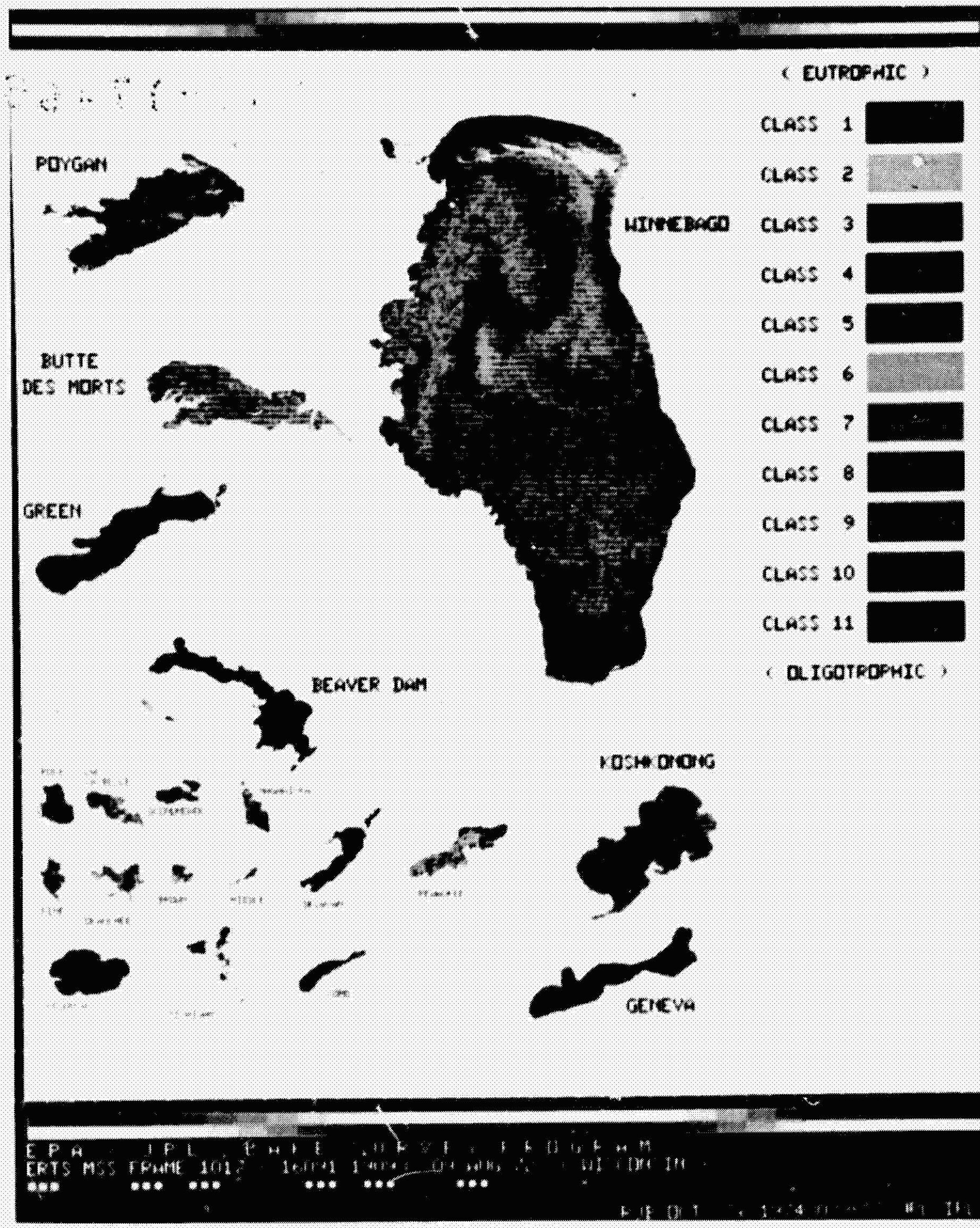


Figure 13. A color-coded concatenation of the 11-class classification of 20 Wisconsin lakes (9 August 1972). The scale labels merely indicate direction on the trophic scale.

E-12

TROPHIC STATUS OF INLAND LAKES FROM LANDSAT

By Lawrence T. Fisher and Frank L. Scarpace, Institute for Environmental Studies,
University of Wisconsin, Madison, Wisconsin

N76-17496

ABSTRACT

A cooperative program between the Wisconsin Department of Natural Resources and the University of Wisconsin's Institute for Environmental Studies has resulted in a first-cut assessment of the trophic status of inland lakes in Wisconsin from LANDSAT data. To satisfy the criteria of the project, a large and versatile computer program to gain access to LANDSAT data was developed. This analysis technique has proven to be a cost-effective method of classifying inland lakes in Wisconsin.

INTRODUCTION

The Wisconsin Department of Natural Resources (DNR) is required to classify the lakes in the state as to their trophic level in response to the federal legislation "Federal Water Pollution Control Act Amendments of 1972," section 314.

This paper describes a cooperative effort between DNR and the University of Wisconsin's Institute for Environmental Studies (IES) to extract LANDSAT data providing a reasonable measure of trophic status in a cost-effective manner. An additional result has been the design of a highly versatile interactive graphics computer program available for both research and agency use.

LANDSAT's multispectral scanner (MSS) simultaneously gathers data at four different wavelengths: Band 4 (.5 to .6μ), Band 5 (.6 to .7μ), Band 6 (.7 to .8μ), and Band 7 (.8 to 1.1μ). A swath 185 km (115 mi) wide is scanned during each orbit, and this is sampled at intervals so that data is recorded for discrete picture elements or pixels whose dimensions are approximately 50 x 70 M.

In this project, Band 5 data was desired because values there can be correlated fairly accurately with lake turbidity. Band 7 data was used to form "pictures" of lakes on a computer terminal. From these, the computer program allowed the terminal operator to select individual picture elements whose data values were punched on cards.

Data was extracted in this fashion for all Wisconsin lakes with areas greater than 20 acres and depths greater than eight feet -- about 3000 lakes in all. The resulting cards were sorted, and lakes within each of Wisconsin's 72 counties were ranked in order of decreasing average Band 5 values.

LAKE TURBIDITY AND LANDSAT DATA

An earlier project (1) investigated relationships between LANDSAT Band 5 brightnesses and lake turbidity. In this project, 37 lakes included in eight different LANDSAT scenes were studied (Figure 1). The northern Wisconsin lakes were generally clear and oligotrophic; those in the southern part of the state range from moderately to highly eutrophic.

Secchi depth readings for each of these lakes were obtained by DNR personnel, but it was operationally not possible to coordinate these tests with LANDSAT overflights. In some instances, over a month's difference existed between secchi depth acquisition and a suitably cloud-free LANDSAT orbit.

Figure 2 shows correlation between LANDSAT Band 5 data and secchi depths for some of these lakes. A definite correlation is evident, and much of the scatter is felt to be due to the time differences described above.

COMPUTER PROCESSING OBJECTIVES

Originally this project involved the densitometric analysis of the photographic rendition of the LANDSAT imagery for all the large lakes in Wisconsin. Difficulties with radiometric quality of 9x9 inch photography and operational problems due to extremely small image sizes of small lakes on 70mm images prompted us to begin development of computer-assisted analysis. Since then, we have expanded the program to provide a highly versatile, general purpose multispectral analysis and data acquisition tool for several users and applications.

The objectives that were envisioned in the design of the program were:

a) Access to small, highly specific subsets of large data sets was needed. We wanted to be able to select, for example, an accurately located single data point in a bay of a lake.

b) Multispectral analysis capabilities were needed for feature selection tasks.

c) Operation needed to be highly interactive, so that options could be selected or changed easily, or feature selection training criteria easily altered under operator supervision, etc.

d) Operator-recognizable displays were needed, for example, to recognize and distinguish lakes, or to estimate acceptability of an experimental classification.

e) Navigational aids were needed to help locate areas of interest.

f) Data histogramming capability was designed to assist in supervised training for feature selection.

g) Use with a variety of data types was desirable. At the moment, the program is being used both with LANDSAT data and digitized aerial photography.

h) The program had to be attractive to a wide range of users. This implied that operation should be easily learned and that the program be extremely tolerant of operator errors.

i) No capital was available for hardware. We were constrained to use existing equipment

INTERACTIVE GRAPHICS PROGRAMMING SYSTEM

We elected to design the program around an interactive graphics terminal, and the Madison Academic Computing Center's Univac 1110 computer. One reason was that several terminals are available on campus and are given excellent software and hardware support. Second, the ability to produce a television-type image during program execution, and the operator's ability to respond to the display, provided us with the man-machine interaction deemed essential. Third, graphics features allowed operator specification of data coordinates, graphical display of data histograms, and similar non-alphanumeric input and output.

We read and decode multispectral data for a fairly large area, retaining data for whatever bands are desired and reading data tapes at any of several possible resolutions. Then a portion of this data is displayed on the terminal by means of an array of characters. Each character is displayed only if a set of tests upon the multispectral data is passed. Complete flexibility is provided in the selection of characters, bands to be tested, and test bounds; all of these can be altered at appropriate points during operation.

Displays can be located anywhere within the region for which data was extracted, and can be shown at any of several resolutions. New displays can be called at any time, perhaps at different resolutions or with different character sets or bounds.

Given a display, data can be extracted simply by pointing at desired points or blocks of

points. Data for all such points is printed, punched if desired, and written into a catalogued file which is available to any other program for additional analysis.

Line printer "maps" duplicating displays and showing all extracted data points can be produced as desired.

Interactive computer terminals are becoming familiar in many applications including remote sensing data analysis. A typical terminal consists of a typewriter keyboard and some form of output device -- usually a typewriter, teletype, or cathode-ray tube display. Programs can be written so that interruptions occur at points where operator intervention is needed. Keyboard responses can allow selection of options, decisions, or input of needed data, usually in response to something computed and displayed by the terminal. Such facilities, with proper programming, can provide substantial versatility and convenience.

Graphics terminals, now becoming common, add some powerful features to basic interactive terminals. In addition to display or input of alphanumeric characters, they allow computer-produced drawings of points or line segments, and operator input of coordinate positions which can be formed into graphs, outline drawings, or complex figures. They also allow for transmission of graphical or two-dimensional data to the computer.

DATA EXTRACTION TECHNIQUES

After locating approximate coordinates of lakes by inspection of 9x9 inch imagery, data from Bands 5 and 7 was extracted. Displays were formed by "level slicing" on Band 7, since very low infrared reflectance of water causes extremely low brightnesses in that band. Although the displays were subject to a large number of geometric distortions, it proved generally easy for the terminal operator to recognize and identify lakes and to decide where to extract data.

Data points were then selected, with an average of three to five points per lake. If ground truth data were available from specified portions of a lake, or depth problems were known to exist, an effort was made to extract data from an appropriate region of the lake. Printer maps were produced to provide a documentary record; these show all lake names and data points. At the end of each run, printed and punched data output was produced.

Typically, one to three LANDSAT CCTs (each comprising a quarter of a scene) were analyzed in each day's operation -- these might include anywhere from one or two up to 50 lakes apiece. Economics of operation were highly dependent upon the number of lakes per scene since tape reading was a major part of computation expense. Detailed costs during a typical production run are shown in Figure 3. This run, lasting 75 minutes, involved loading one tape and reading only one portion of it. Ten full and partial displays, and nine printer maps (each including at least one lake) were produced. The total computation charge (using late night computer rates) was just under $6.00.

Overall, about $4,000 of computer time and $6,000 for operator salaries were required to obtain data for the 3,000 lakes.

PRODUCTS AND CONCLUSIONS

Results supplied to DNR include, first, a machine-produced tabulation of lakes in each of 72 counties, listing in order of decreasing Band 5 reflectance and therefore at least approximately in order of decreasing turbidity; and a 35mm microfilm copy of all printer maps produced, showing locations of all data points. A sample output for one county is included in Table I.

Another result has been the computer program itself, which is now being used for research activities by DNR personnel. [illegible] [illegible]ipate that it will become an operational tool used by DNR staff for similar or related analysis.

FUTURE WORK

A much more extensive ground truth effort is now being planned, in which DNR field staff will be obtaining secchi depths and related data in conjunction with LANDSAT overflights.

Navigation procedures are being developed to allow coordinate transformations from scene to scene. These will be used to inexpensively obtain additional data over the course of a full season. Also, data from bands other than Band 5 will be incorporated. This multispectral multitemporal analysis is expected to yield better measures of trophic status.

SUMMARY

A cooperative program involving University researchers and natural resource managers has utilized LANDSAT data to produce an economical trophic status assessment of 3000 Wisconsin lakes. Computer programs have been developed which allow easy, rapid access to LANDSAT data and which can be used by non-research personnel for production data extraction. Capital expenses are low, and operating costs are very reasonable compared to expenses to acquire on-site data of comparable quality.

REFERENCES

1. F. Scarpace, L.T. Fisher, and R. Wade, "Lake Classification Using ERTS Imagery," Proc. Symp. on Remote Sensing and Photo Interp., Comm. G, ISP, Banff, Alberta, Canada, Oct. 1974.

2. A.N. Williamson, "Mapping Suspended Particle and Solute Concentrations from Satellite Data," U.S. Army Engineer Waterways Experiment Station Report (1974).

TABLE 1.- SAMPLE OUTPUT SUPPLIED TO DNR: ALL LAKES IN COLUMBIA COUNTY RANKED IN DECREASING ORDER OF AVERAGE BAND 5 REFLECTANCE

RANK	LAKE NAME	NUMBER OF POINTS	BAND 5 AVERAGE	BAND 5 RANGE	SCENE IDENTIFICATION
1	Swan	4	16.50	16 - 18	1378-16151 3
2	Long	2	15.50	14 - 17	1378-16151 3
3	Lazy	3	14.67	14 - 15	1378-16151 3
4	Park	4	14.50	14 - 15	1378-16151 3
5	Spring	3	14.00	14 - 14	1378-16151 3
6	Lake Wisconsin	9	14.00	13 - 15	1378-16151 3
7	Becker	2	13.50	13 - 14	1378-16151 3
8	Silver	2	13.50	13 - 14	1378-16151 3
9	George	2	13.50	13 - 14	1378-16151 3
10	Wyona	2	13.50	13 - 14	1378-16151 3
11	Crystal	1	13.00	13 - 13	1378-16151 3

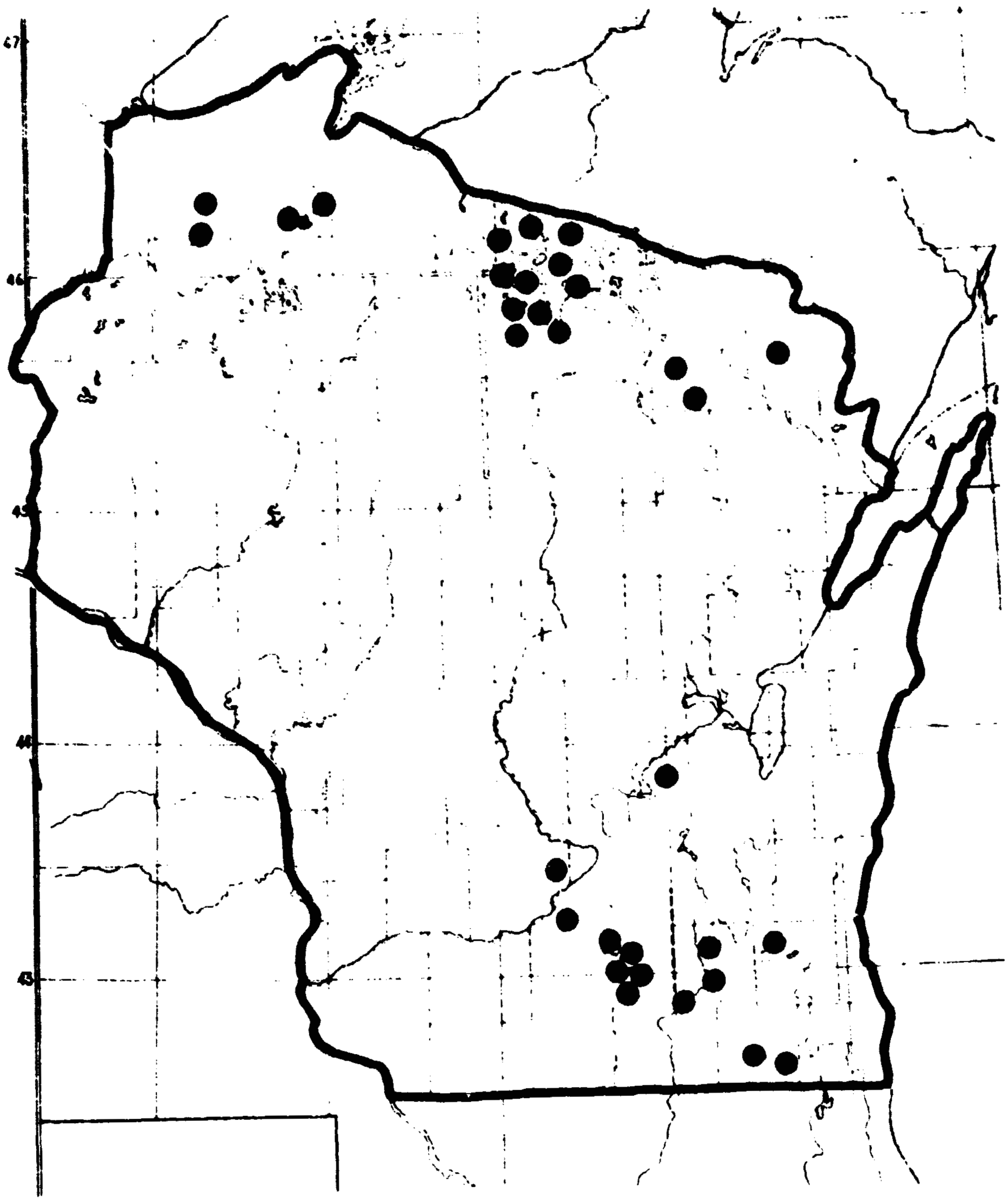


Figure 1--Map of Wisconsin Showing Locations of Lakes Sampled by the Wisconsin Department of Natural Resources

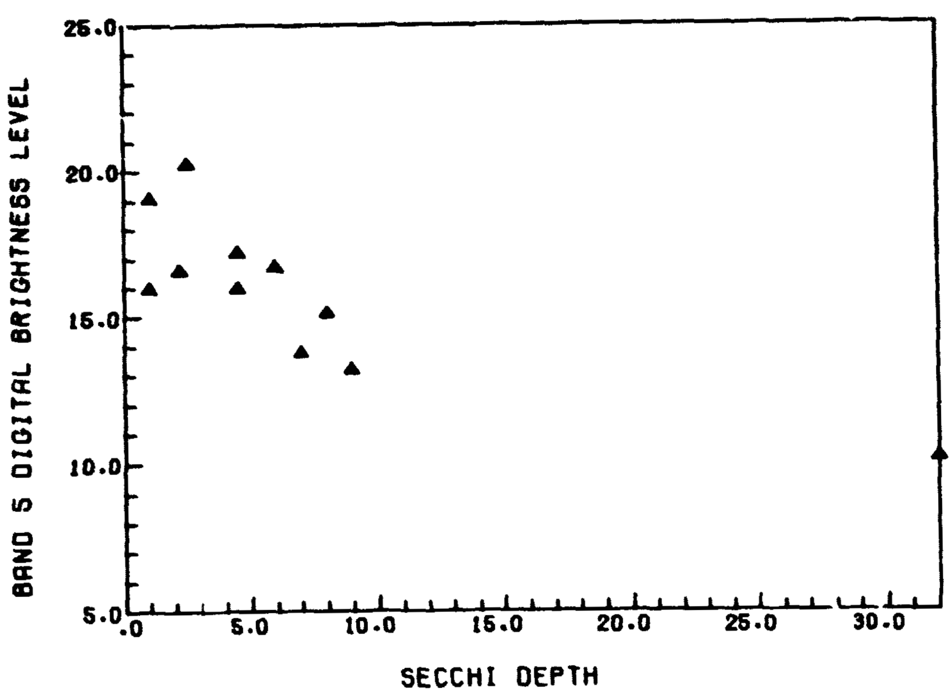


Figure 2--Correlation Between Band 5 Brightnesses and Secchi Depths for 17 Test Lakes

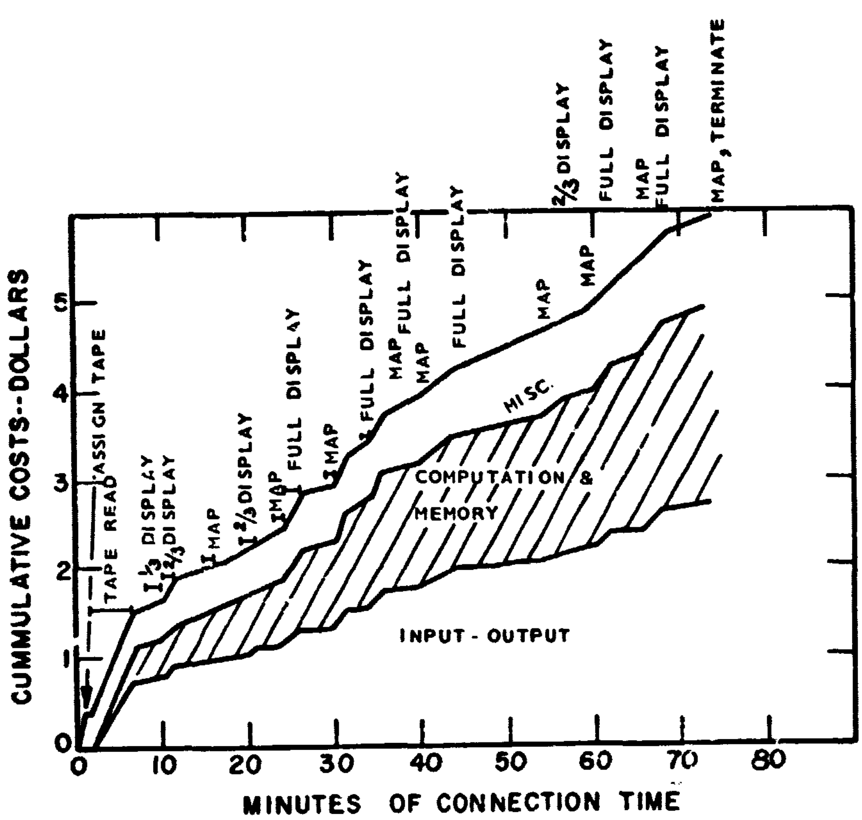


Figure 3--Computer costs for a Typical Production Run for Lake Classification.

THE USE OF LANDSAT-1 IMAGERY FOR WATER QUALITY STUDIES IN SOUTHERN SCANDINAVIA **E-13**

By Ulf Hellden, Department of Physical Geography, University of Lund, Sweden

ABSTRACT

In order to find out the possibilities of using LANDSAT-1 images for environmental studies, with special references to water quality studies, test areas in southern Scandinavia have been selected.

The MSS images of different bands are compared under the magnification of an Interpretoscope (Zeiss Jena) and densitometric analyses are performed in a Schnell-photometer (Zeiss Jena).

The possibility of tracing pollution plumes is studied in the Oresund outside Copenhagen. The effect of different sewers and the circulation of the polluted water is analysed in various situations.

The variation in reflectivity of a great number of lakes in South and Middle Sweden is studied by means of densitometric analyses and significant regional differences are found. The correlation with in situ measurements of water quality (turbidity and secchi disc transparency) of the sampled lakes (made by the National Swedish Environment Protection Board) is fair good.

INTRODUCTION

In order to find out the possibilities of detecting and determining quantitatively water qualities by means of LANDSAT-1 data, the sewage conditions of Copenhagen in the Oresund and 161 lakes in South and Middle Sweden have been chosen as material to be investigated.

According to spectral experiments accounted for by Fitzgerald (1972), chlorophyllic water reflects most intensively within the band 0.4-0.6 μm, while industrial water pollutions reach their highest reflection in the band 0.6-0.7 μm. Since solar radiation within the MSS bands 4 and 5 have a higher degree of penetrating power into water than within the bands 6 and 7, the former are probably the most suitable channels for water quality detection. The two latter bands are suitable for the detection of surface water quality only.

The investigation has been carried out at the Remote Sensing Division of the Department of Physical Geography, University of Lund, Sweden, within the NASA sponsored project "Evaluation of Data Utility for Earth Sciences from a Methodical Point of View."

METHODS

All the images of the Copenhagen area which have been obtained within the LANDSAT-1 project, have been analysed in an Interpretoscope (Zeiss Jena), whose zoom construction has admitted an adequate choice of enlargement up to 15 times. The types of images that have been investigated, are paper copies and dia-positives of the standard scale 1:1 000 000, which cover the period September 1972-August 1973. From this material four dia-positives (September 1, September 2, 1972, and May 30, August 27, 1973) have been selected and investigated in a microdensitometer (Schnellphotometer G II with Standard-Kompensationsschreiber GI BI), whereby the grey-tone variations in the water outside Copenhagen have been recorded by the plotter unit. A column width of 1 x 1 mm has been used to obtain the required sensitivity to light. As the densitometer measures the transmission of a projection of a dia-positive, which is enlarged 21 times in the projection, the column at a certain moment scans an area 50 x 50 m. The resolution in the images is usually specified 56 x 79 m. However, when the contrasting effect is very good, the resolution may show considerably higher values. For example, it has been possible to detect elongated harbor piers, belonging to a Swedish west-coast town (Halmstad), 50-20 miles wide.

Then the obtained transmission values have been plotted on an image of the Copenhagen area, enlarged from MSS 7, isarithms have been constructed and pollution plumes drawn. In order that the obtained measurement values of the grey-tone variations may be comparable from one image to another, the densitometer has been calibrated to the grey-tone scale contained in each LANDSAT-1 image.

After having examined Swedish lakes in Interpretoscope, they turned out to vary in grey-tone to a lower or higher degree (Fig. 1-2). Since the production of algae and plankton in the lakes of Sweden is greatest in the summer, as large a number of images as possible of South and Middle Sweden were chosen, partly from the turn of month June/July 1973 and partly from the turn of month August/September of the same year. The imagery was analysed in a densitometer for MSS 4 and MSS 5, and thereby the grey-tone of each lake was measured at 5-10 different points and a mean value for each was calculated. For the period June/July, 113 lakes were analysed in MSS 4, while 161 lakes were examined for the period August/September in MSS 4 and the same number in MSS 5. Also in this case, the grey-tone scales were used in order to calibrate the densitometer in such a way that the test results from different images could be compared.

The obtained grey-tone values have been inserted on a map of the lakes of South and Middle Sweden, after which isarithms have been interpolated. The map is constructed in such a way that areas with lakes of the same grey-tone class are reproduced with the same screen pattern, irrespective of if the area in question is represented by one or several lakes, which means that vast land areas situated between classified lakes have been screened, too.

SOURCES OF ERROR

Since analyses of water quality are best carried out using images from MSS 4 and MSS 5, channels in which smoke plumes, clouds and belts of fog also appear most distinctly, it is self-evident that problems of interpretation and pure errors in

measurements may occur. Smoke and cloud sheets, even thin ones, of fairly large extension can, however, be detected by means of comparative analyses of images from different MSS bands (Mattson 1973, Svensson et al. 1974). Thin belts of smoke, clouds or fog of limited extension over a water surface are easily misinterpreted as the grey-tone of the water. But, in general, fog or cloud covered water surfaces are recorded by the densitometer with extremely high transmission values, which deviate very much from those of the surrounding water.

In the cases where images from the same period, which partially cover the same areas, can be used, there are also possibilities of detecting and eliminating the effect of smoke, cloud and fog belts on the test results through the exclusion of the higher transmission values (lighter grey-tones) caused by the above mentioned belts.

As mentioned, it is registrations from the band 0.5-0.7 μm that are analysed in order to obtain information about the water quality. Thus, that which has been recorded is radiation, which has penetrated the water surface to a higher or lower degree and has been reflected from substances in the water, alien and/or produced in a natural way. It is also possible that the bottom of shallow lakes have been registered and misinterpreted as the grey-tone of the lake.

Under certain circumstances, however, water surfaces serve as mirrors and reflect the sunlight totally, which produces sunglitter. This sunglitter stands out, e.g. on an aerophoto positive, as light surfaces on the water. This mirror reflection has been pointed out, among others by Strong et al. (1970) in ESSA-9 satellite photos and has been utilized as an indication of water surface roughness and the prevailing wind speed. Sun glitter of this type, however, is not admitted by the multispectral scanner of LANDSAT-1, since the true total reflection point for higher latitudes lies several hundred kilometers from the nadir and the width of the obtained registrations is only 185 km (Stumpf et al. 1974). A certain diffuse surface reflection may occur, but it makes up such a small part of the total reradiation that it need not be considered as a source of disturbance.

RESULTS

Analyses of the pollution situation outside Copenhagen.- The principal part of Copenhagen's waste water is today let out quite unpurified through two main pipes into the eastern part of Kongedybet at a depth of 6-10 m. The pump station at Strandvaenget, from which the three pipes radiate (in Fig. 3 situated to the north), lets out 14.0 million m^3 waste water per annum, while the corresponding figure for Klovermarksvejen's pump station, from which the sewer situated to the south in Fig. 3 comes, is 40.0 million m^3 per annum (Dackman et al. 1971). The quantity of phosphorous and nitrogen from the respective pipes was in 1973 320 tons and 1000 tons respectively 510 tons and 1600 tons (Environment Committee of the Oresund Board 1974). The two pipes from Strandvaenget which are situated furthest to the north, are day-water sewers and are in use only when the supply of rainwater is considerable.

The pollution situation on September 1, 1972, is evident from Fig. 3. The figures on the plumes indicate the relative transmission, which has been registered by the densitometer on the dia-positive and, accordingly, in a measure of the grey-tone differences within the area. Lighter grey-tones result in higher

transmission values. The isolines indicate the distribution and the relative concentration of the pollutions. The other three images that have been analysed show similar conditions, although the spread picture and the distribution of concentration vary somewhat. In general, it can be stated that the plumes on all the images investigated are more or less elongated in a N-S direction along Kongedybet and that the highest transmission values vary between 60% and 80% (Fig. 4-6).

On the images from May 30 and August 27, 1973, there is a very marked plume situated 300-500 miles to the east of the northernmost outlets (the day-water sewers), while the plume at the middle sewer has a very limited expansion. This is interpreted in such a way that the day-water pipes have drained the main part of Strandvaenget's waste water after intensive and/or prolonged precipitation.

Water quality studies of lakes in southern and middle Sweden.- How the difference in grey-tones can vary between two neighboring lakes is illustrated in Fig. 7(cf 1). The diagrams show densitometer profiles drawn over the lakes Vastra and Ostra Ringsjon in Scania for MSS 4 and MSS 5. The transmission values of Lake Vastra Ringsjon (V.R.) are higher than those of the lake Ostra Ringsjon (O.R.). In channel 5, the profiles are more levelled out and the differences between the two lakes are not so pronounced as in channel 4.

The map in Fig. 8 shows land areas with lakes of the same grey-tone class, where the given figures are the transmission values obtained after densitometer analyses. In the hatched area, 161 lakes have been analysed in channel 4 on diapositives from August 26, August 27 and September 4, 1973. Non-hatched areas denote areas where it has not been possible to measure the grey-tones of the lakes owing to too dense cloudiness. The high values in Scania should be noted, likewise those in the area around Lake Roxen and Lake Glan, the Lakes Hjalmaren and Malaren and within an area that stretches down from Lake Vanern towards the area WSW of Lake Vattern. Likewise, the lowest classes, i.e. the area at Bohuslan-Dalsland in north-west and the three areas SE of Lake Vattern.

Then the map can be compared with Fig. 9, which is a compilation by the National Swedish Environment Protection Board of the secchi disc transparency in Swedish lakes. The data basis for this map was collected in August 1972 by the County Administrations of Sweden, who by order of the National Swedish Environment Protection Board and as far as supplies allowed investigated at least 50 lakes in each county among other things with regard to secchi disc transparency, turbidity, color, oxygen content, total phosphorous content, pH and alkalinity (Johansson et al. 1974). Parts of the collected analyses values have kindly been covered by the research laboratory of the National Swedish Environment Protection Board and after continued working up they will be used for comparisons with the spectral properties of the lakes, detected in the densitometer.

A similar image as in Fig. 8 is produced after the analyses of the corresponding material in MSS 5 (Fig. 10). Since more of the radiation reaching water within the band 0.6-0.7 μm, compared with the band 0.5-0.6 μm, is absorbed in the top water layers, the recorded transmission values become considerably lower than the ones within the band last mentioned (MSS 4). Since color radiation within the former band has lower penetrating power into water than within the latter, figure 10 probably reflects to a larger degree the water quality conditions of the surface layers of the examined lakes than figure 8 does.

Figure 11 shows the results of the analyses of LANDSAT images (MSS 4) from the turn of month June/July, 1973 (June 18, July 3) and gives in a general outline

the same image as figure 8 except for certain regional differences. Owing to too dense cloudiness over large parts of western Sweden, the measurements are incomplete. It is, however, possible to observe that Scania, the area round Lake Roxen and Lake Glan and the Hjalmaren-Malaren area are depicted with the highest screen classes, while the lowest screen classes can be seen in the Bohuslan-Dalsland-Varmland area. It should be noted that the area to the south-east of Lake Vattern (Fig. 8) which has been labelled with low values, has received far greater extension in figure 11, and that the low values have been replaced by high ones. The differences between the maps can possibly be explained by the fact that the water quality conditions of the investigated lakes probably alternate with the seasons and, therefore, are probably different at the end of August and at the turn of month June/July. Since ground truth information from the latter period is lacking, comparisons between the two maps must be made with certain care.

The results hitherto obtained indicate that there might be a relationship between the grey-tones and secchi disc transparency of the analysed lakes (lighter grey-tones correspond to low secchi disc transparency). Therefore, the grey-tones of the LANDSAT images can primarily be assumed to be a measure of the transparency of the lakes and indirectly a relative measure of the water turbidity, content of algae and plankton on the occasions of the satellite registrations. The transparency of a lake at a certain date can be considered a measure of the biological-chemical conditions of the lake and can probably be correlated to other limnological parameters.

DISCUSSION AND COMPARISONS

Detection of water pollution by means of satellite-borne sensors has been described by among others Watenabe (1973) and Werzenek et al. (1973). Any methodology for a relative analyses or absolute quantification of sewage plumes has, as far as known, not yet been presented in the literature.

Detection of the turbidity and/or chlorophyllic content (algae, plankton) in water bodies has been made in several cases (Bowker et al. 1973, Pluhowski 1973, Svensson 1973). Thus Yarger et al. (1973) has examined the two water reservoirs Perry and Tuttle Creek, Kansas, U.S.A. with regard to grey-tone variations on LANDSAT-1 images and thereby they have been able to find certain connections between grey-tones, quantity of suspended material and secchi disc transparency.

More detailed information about water qualities can probably be derived from LANDSAT data through automation of the procedure of analyses from digital tapes (CCT), whose grey-tone differentiation is almost eight times greater than that of the photographic products (Kritikos et al. 1974). Therefore, at the beginning of 1975, cooperation with the Image Processing Department of the National Defense Research Institute regarding automatic evaluation of MSS computer compatible tapes with respect to information from water bodies was introduced. The results from these experiments are still preliminary and, therefore, only a computer produced microfilm image is presented (Fig. 12). The pollution conditions off Copenhagen on August 27, 1973, are evident from the figure. The grey-tone differentiation of the water has been enhanced and the image has been produced with the help of a Calcomp 835 microfilm plotter.

The possibilities of acquiring continuous information quickly and effectively regarding the quality of different water bodies by means of multispectral images from future operative earth resources satellites are judged to be very good after a further development of existing methods.

REFERENCES

Bowker, D. E., Fleisher, P., Gosink, T. A., Hanna, W. J., Ludwick, J. 1973: Correlation of ERTS multispectral imagery with suspended matter and chlorophyll in Lower Chesapeake Bay. Symp. on Sign. Results obtained from the ERTS-1. Vol. I, 1291-1298.

Dackman, T., Ronne, V. R. 1971: Kommunernas aflob. Oresundsvattenkommittens undersokningar 1965-1970. AB Allmana Forlaget, Stockholm, 301-311.

Fitzgerald, E. 1972: Multispectral scanning systems and their potential application to earth resources surveys. Vol. 2, Chapter 5. Plessey Radar, 121-172.

Johansson, K., Karlgren, L. 1974: Tusen sjoar. Rapport fran en inventering. Statens Naturvardsverk. Publikationer 1974:11.

Kritikos, H., Yorinks, L., Smith, H. 1974: Suspended solids analyses using ERTS-A data. Remote sensing of environment. Vol. 3, Nr. 1, 69-78.

Mattsson, J. 1973: Molnstudier med bilder fran ERTS-1. Rapp. och Not. fr. Lunds Univ. Naturgeogr. Inst. Nr. 19.

Oresundsradets miljoutskott 1974: Oresunds vatten. Information fran Oresundsradets miljoutskott, April 1974.

Pluhowski, E. J. 1973: Remote sensing of turbidity plumes in Lake Ontario. Symp. on Sign. Results obtained from the ERTS-1. Vol. I, 837-846.

Strong, A. E., Ruff, I. S. 1970: Utilizing satellite-observed solar reflections from the sea surface as an indicator of surface wind speeds. Remote sensing of environment. Vol. I, Nr. 3, 181-186.

Stumpf, H. G., Strong, A. E. 1974: ERTS-1 views on oil slick? Remote sensing of environment. Vol. 3, Nr. 1, 87-90.

Svensson, H. 1973: Vattenkvalitet och stromningsmonster i Hanobukten, observerade i ERTS-1 bilder. Svensk Geografisk Arsbok 49, 209-211.

Svensson, H., Olsson, H-A. 1974: ERTS-1 data for miljovardsapplikationer. S.N.V. PM 518.

Watenabe, K. 1973: Polluted and turbid water masses in Osaka Bay and its vicinity revealed with ERTS-A imageries. Symp. on Sign. Results obtained from the ERTS-A. Vol. I, 681-687.

Werzenak, C. T., Roller, N. 1973: Monitoring ocean dumping with ERTS-1 imagery. Symp. on Sign. Results obtained from the ERTS-1. Vol. I, 635-642.

Yarger, H. L., McCauley, J. R., James, G. W., Magnuson, L. M., Marzolf, G. R. 1973: Water turbidity detection using ERTS-1 imagery. Symp. on Sign. Results obtained from the ERTS-1, Vol. I, 651-658.

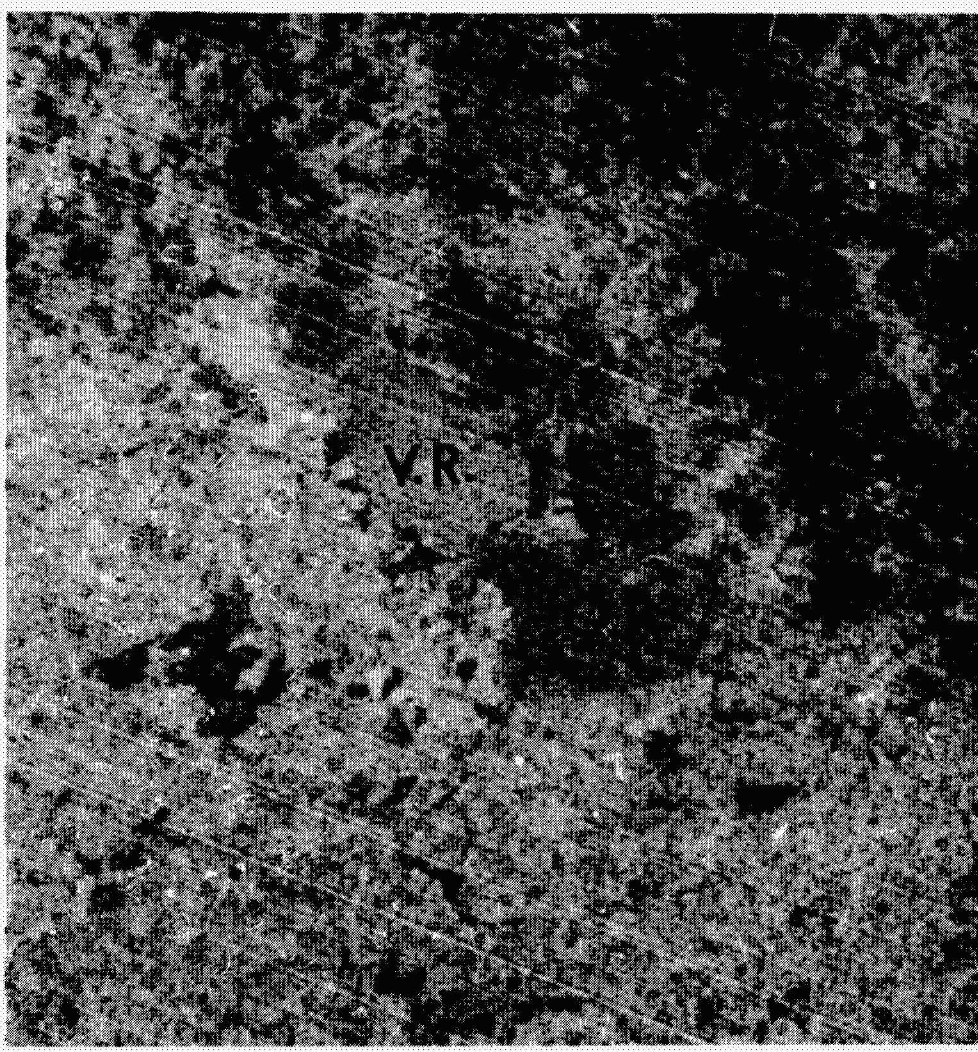


Figure 1.- LANDSAT-1 image (MSS 4) of Lake Ostra Ringsjon (O.R.) and Lake Vastra Ringsjon (V.R.) in Scania registered on August 27, 1973. Appr. scale 1:650,000.

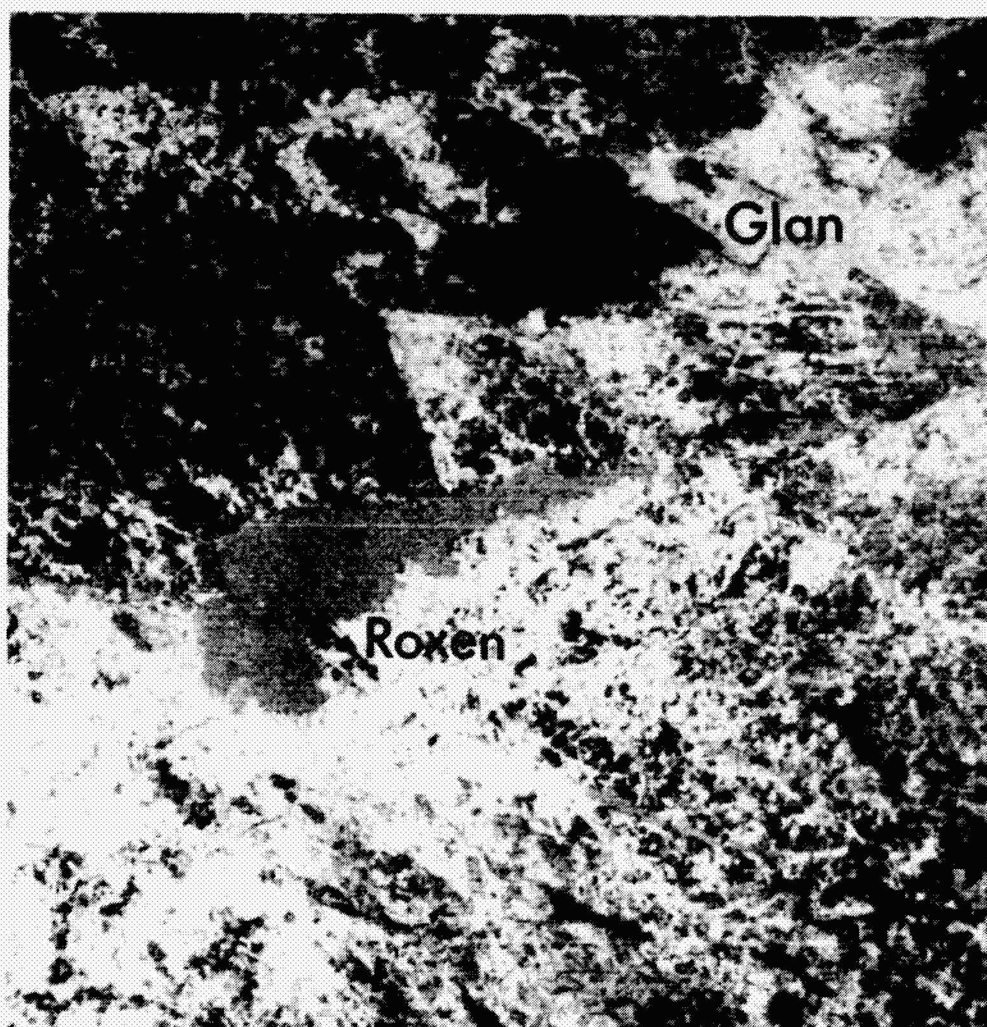


Figure 2.- LANDSAT-1 image (MSS 4) of the Lakes Roxen and Glan in Ostergotland, registered on August 27, 1973. Appr. scale 1:650,000.

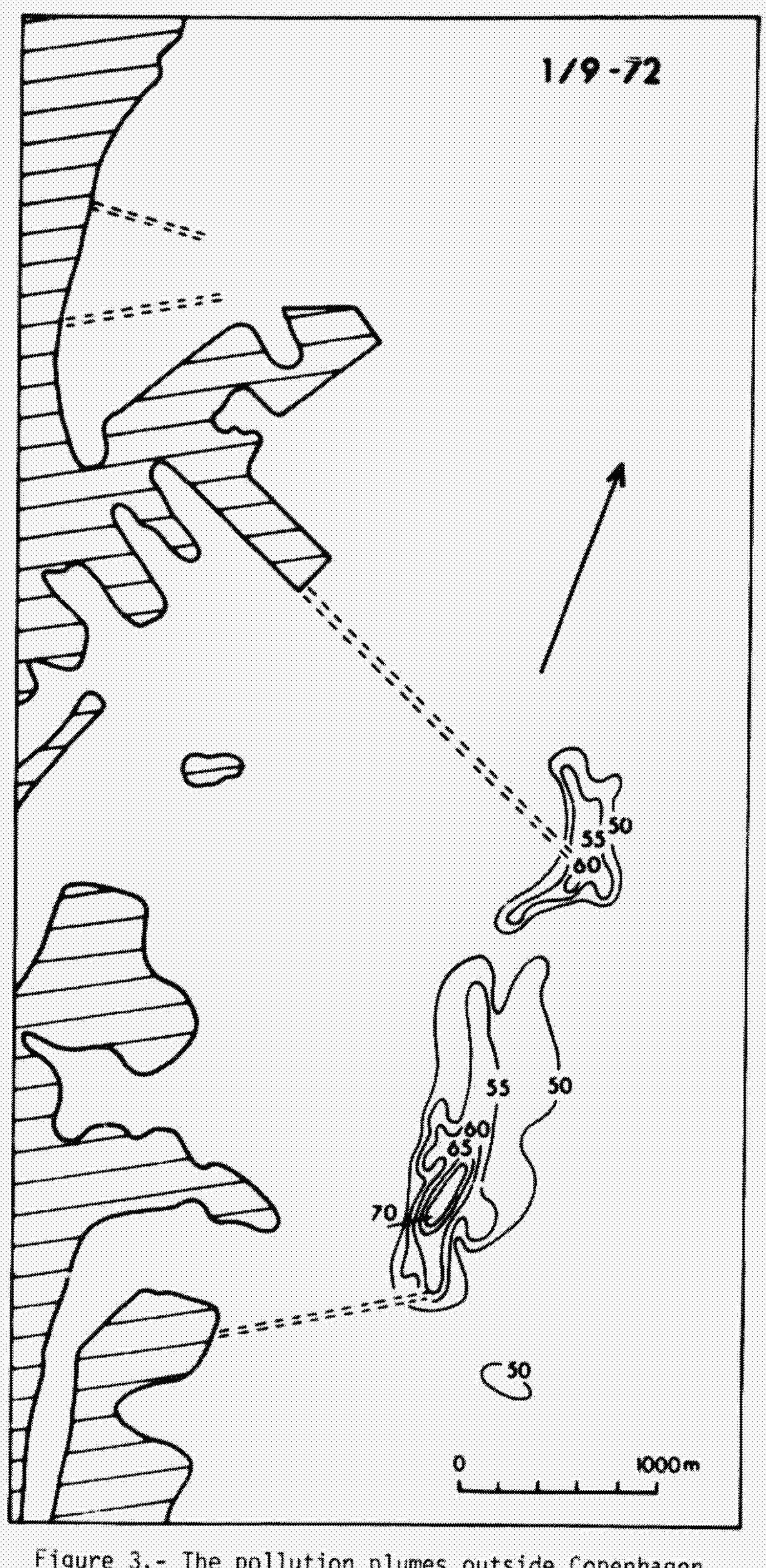


Figure 3.- The pollution plumes outside Copenhagen on September 1, 1972, according to densitometer analysis of LANDSAT-1 diapositive (MSS 5). The figures denote the relative transmission.

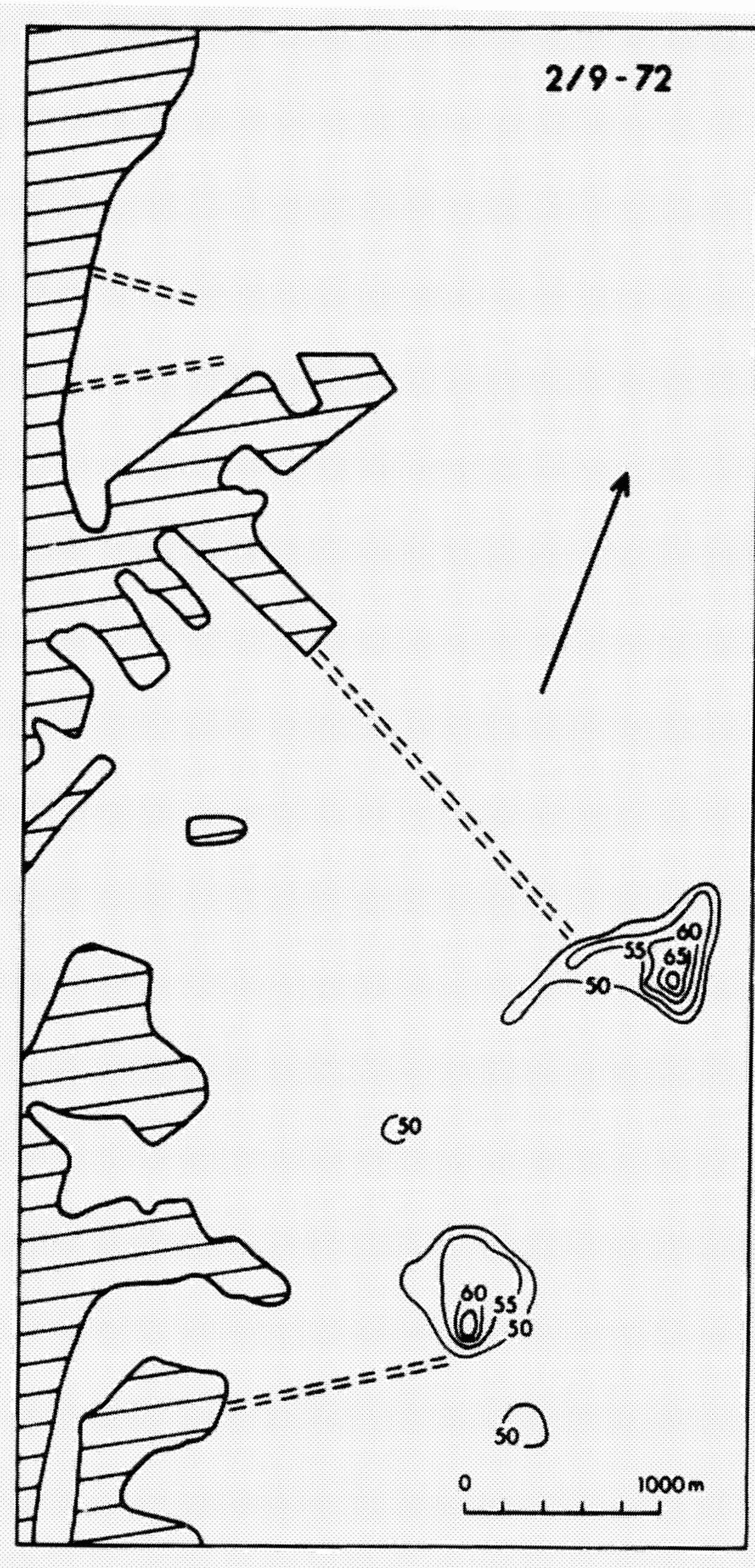


Figure 4.- The pollution plumes outside Copenhagen on September 2, 1972, according to densitometer analysis of LANDSAT-1 diapositive (MSS 5). The figures denote relative transmission.

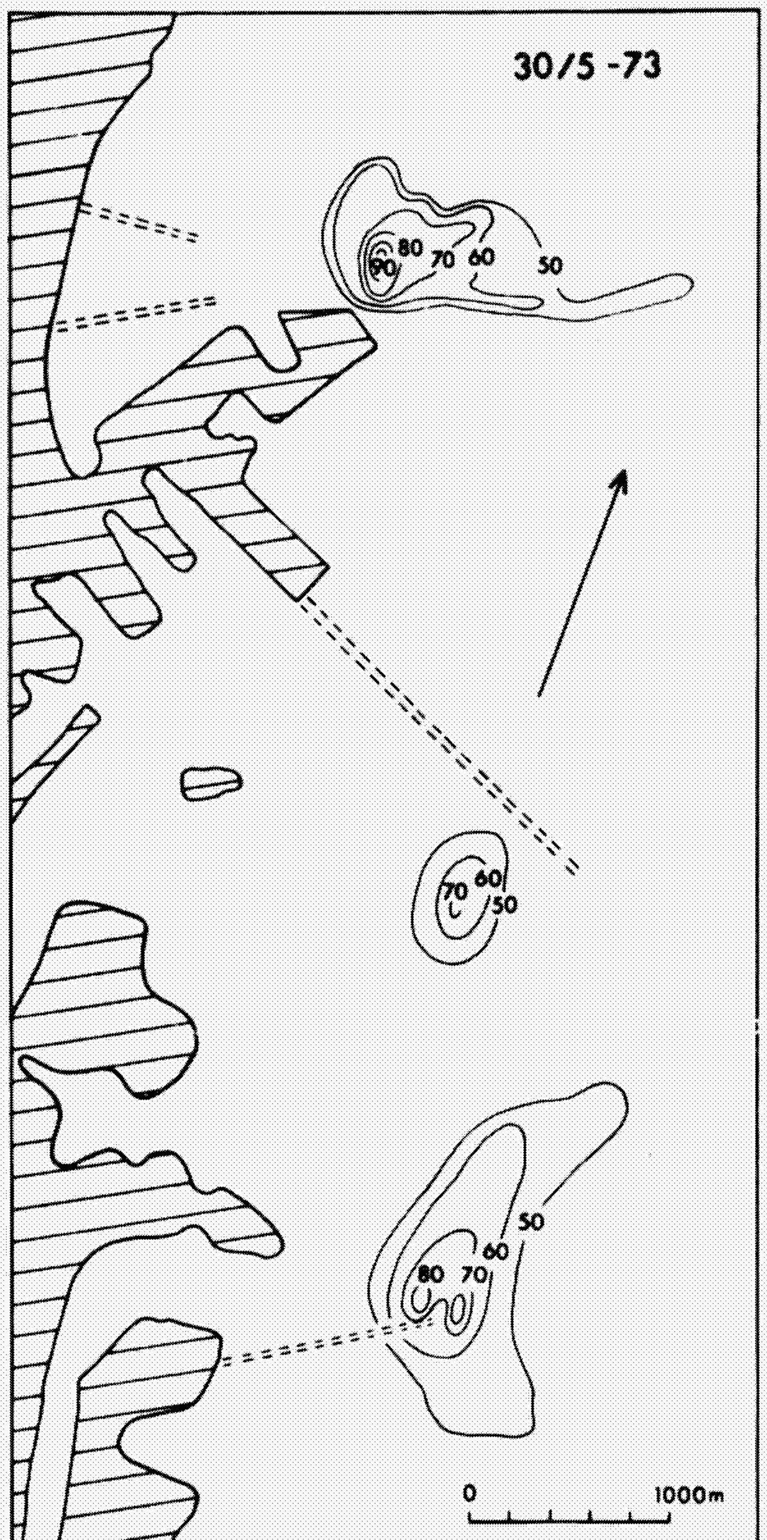


Figure 5.- The pollution plumes outside Copenhagen on May 30, 1973, according to densitometer analysis of LANDSAT-1 dia-positive (MSS 5). The figures denote the relative transmission.

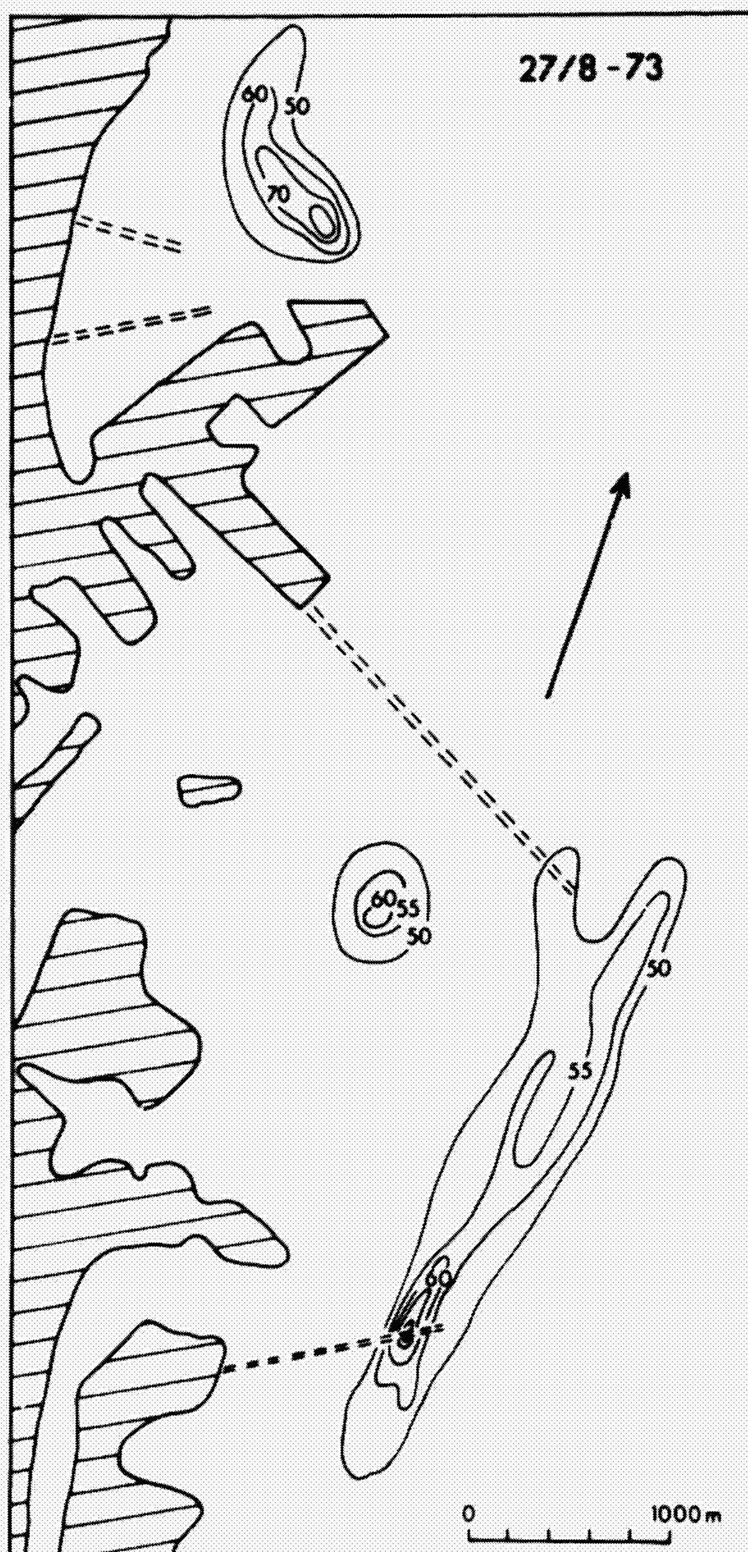


Figure 6.- The pollution plumes outside Copenhagen on August 27, 1973, according to densitometer analysis of LANDSAT-1 diapositive (MSS 5). The figures denote the relative transmission.

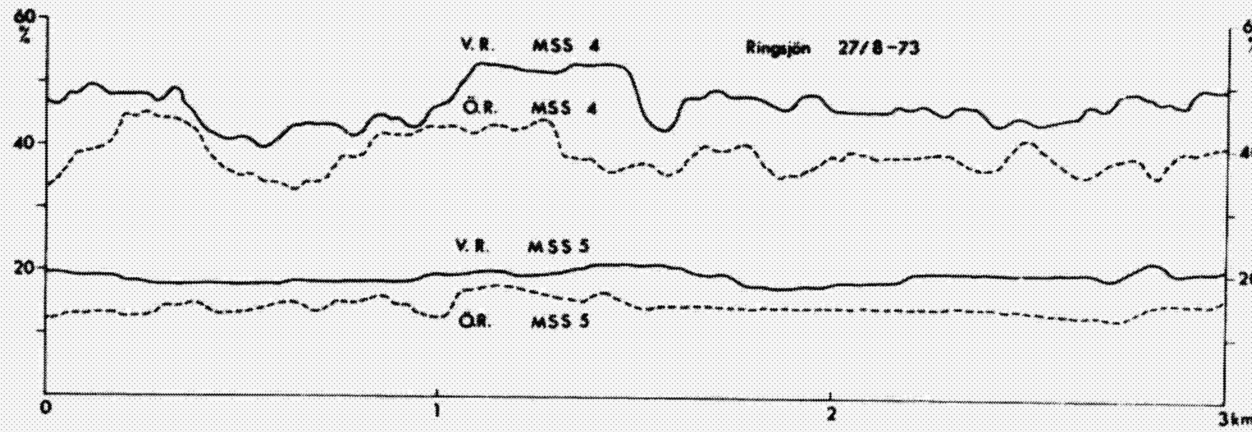


Figure 7.- Densitometer profiles of Lake Vastra Ringsjon (V.R.) and Lake Ostra Ringsjon (O.R.) in Scania on the basis of LANDSAT-1 images (MSS 4, MSS 5) registered on August 27, 1973.

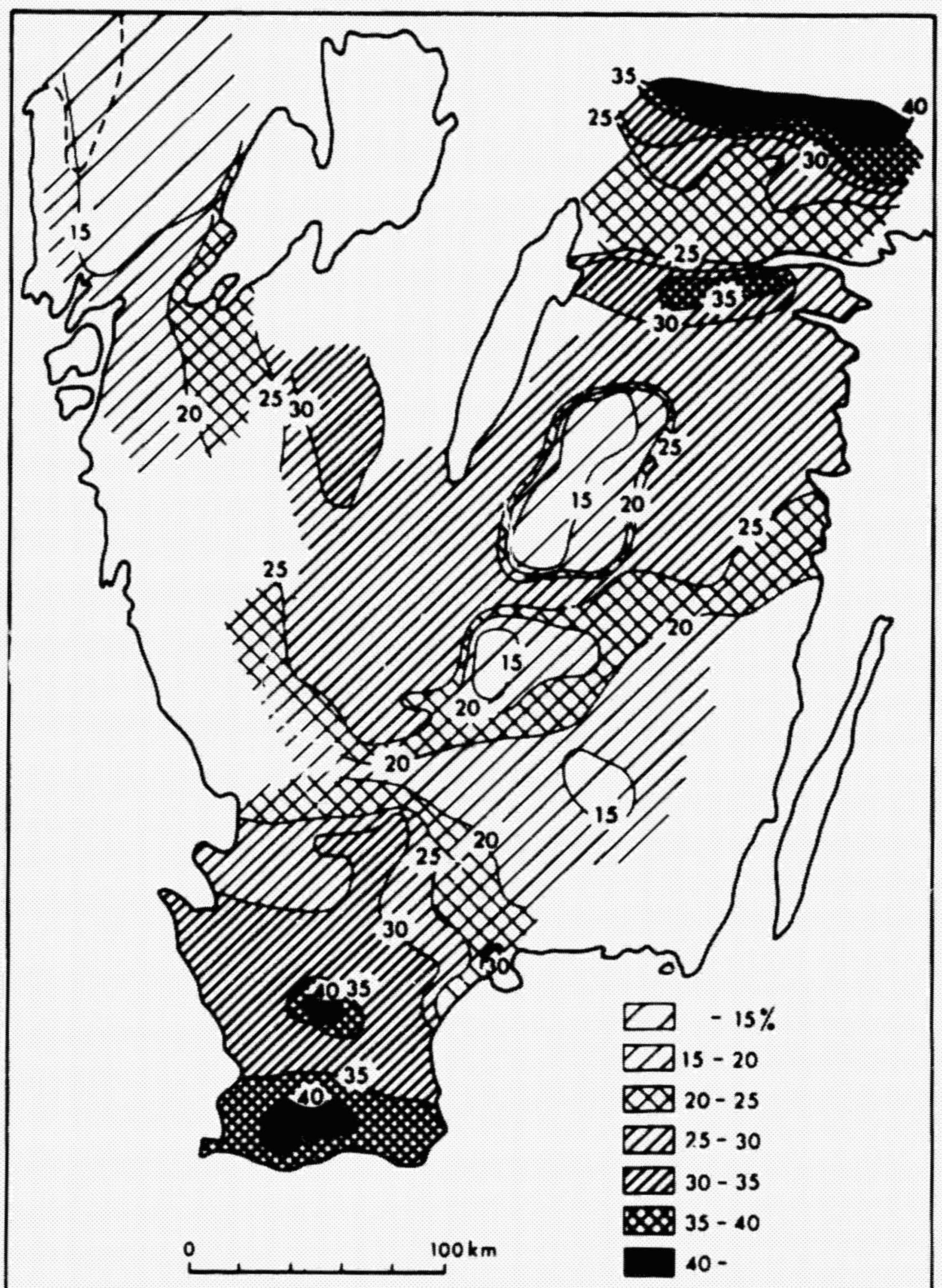


Figure 8.- Map of land areas with lakes of the same grey-tone where the given figures represent transmission values gained after densitometer analysis of LANDSAT-1 images (MSS 4) registered on August 26, 27 and September 4, 1973.

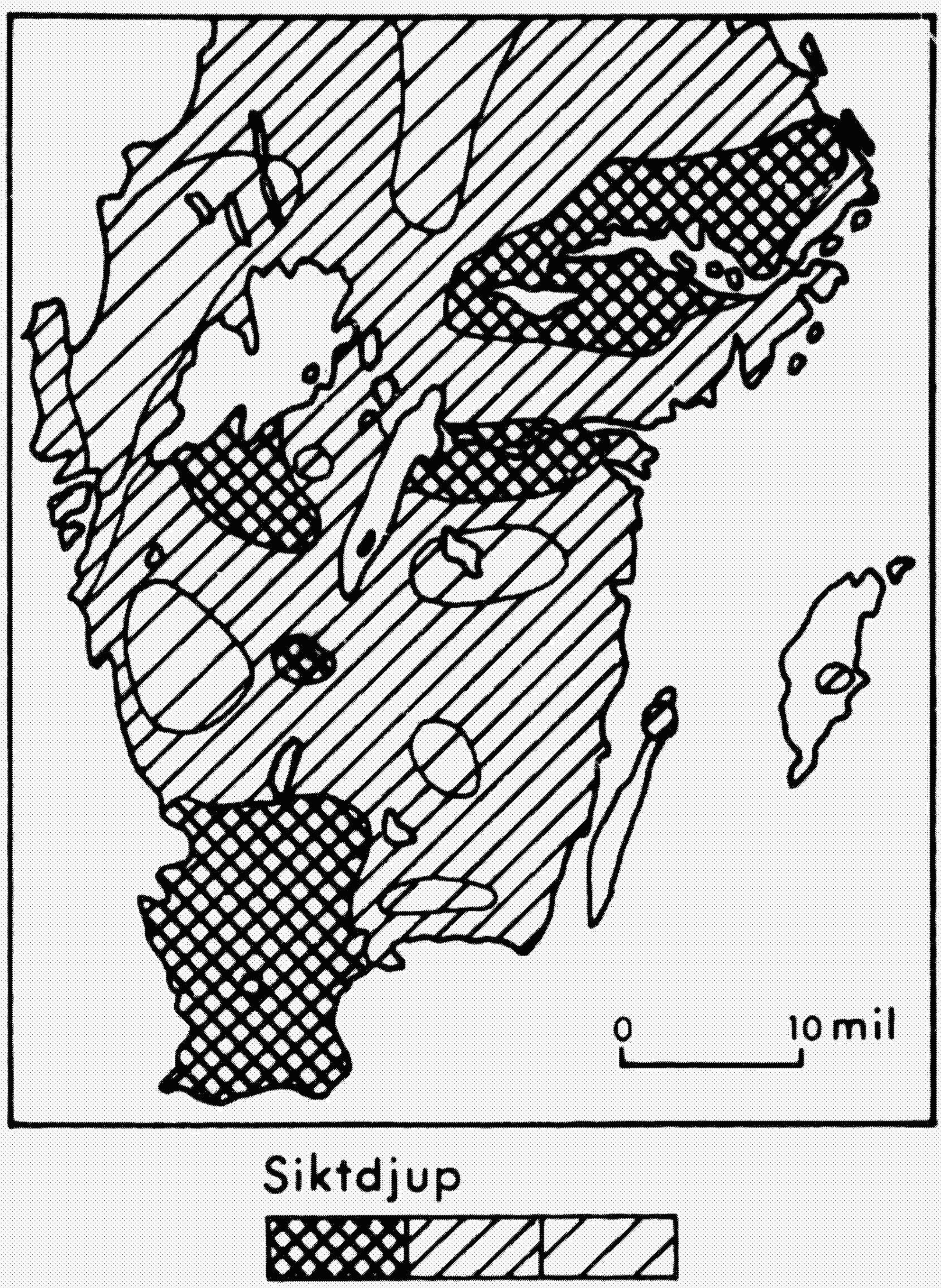


Figure 9.- The secchi disc transparency of Swedish lakes based on a compilation of the National Swedish Environment Protection Board (after Johansson et al. 1974).

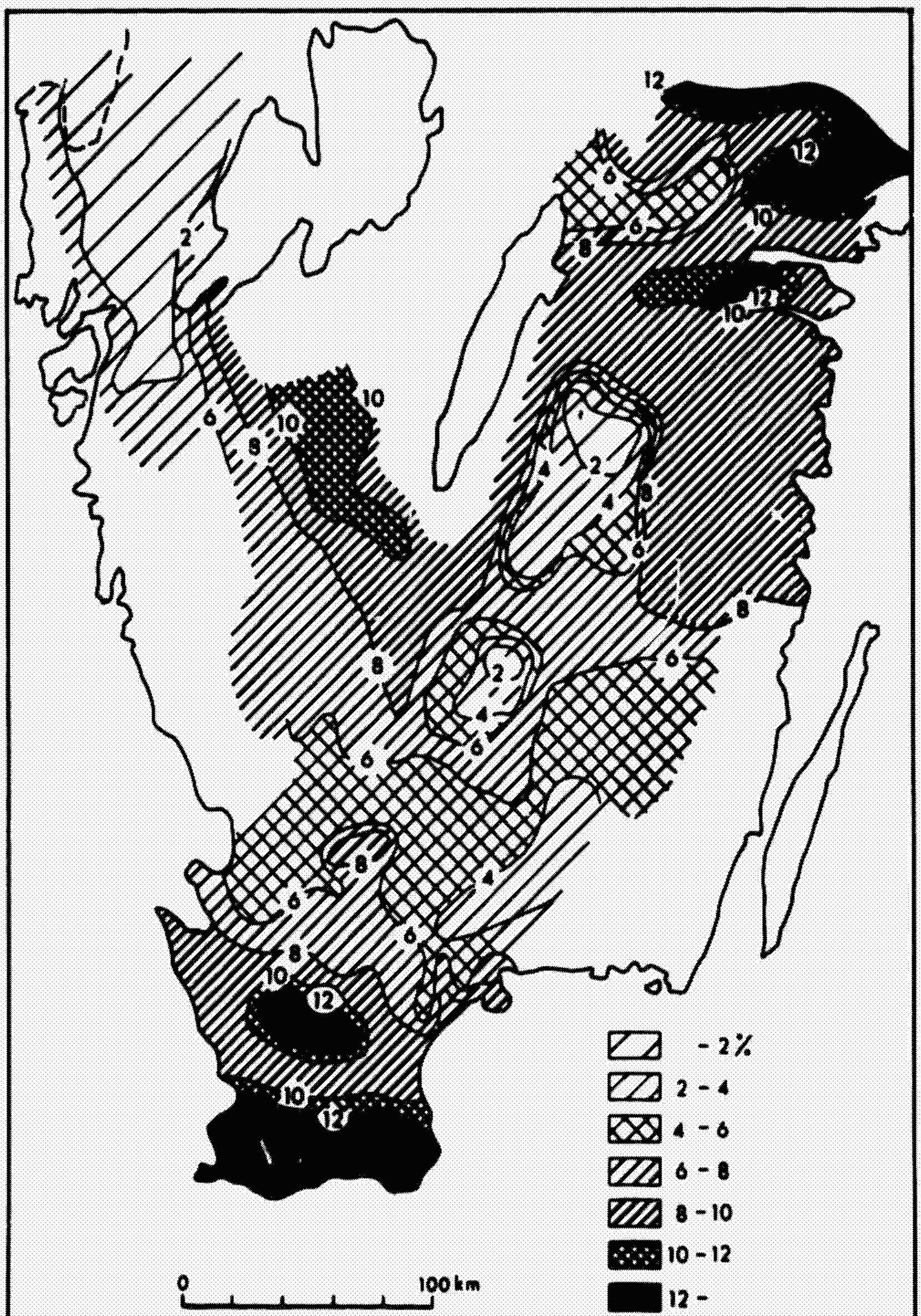


Figure 10.- Map of land areas with lakes of the same grey-tone class where the given figures represent transmission values gained after densitometer analysis of LANDSAT-1 images (MSS 5) registered on August 26, 27 and September 4, 1973.

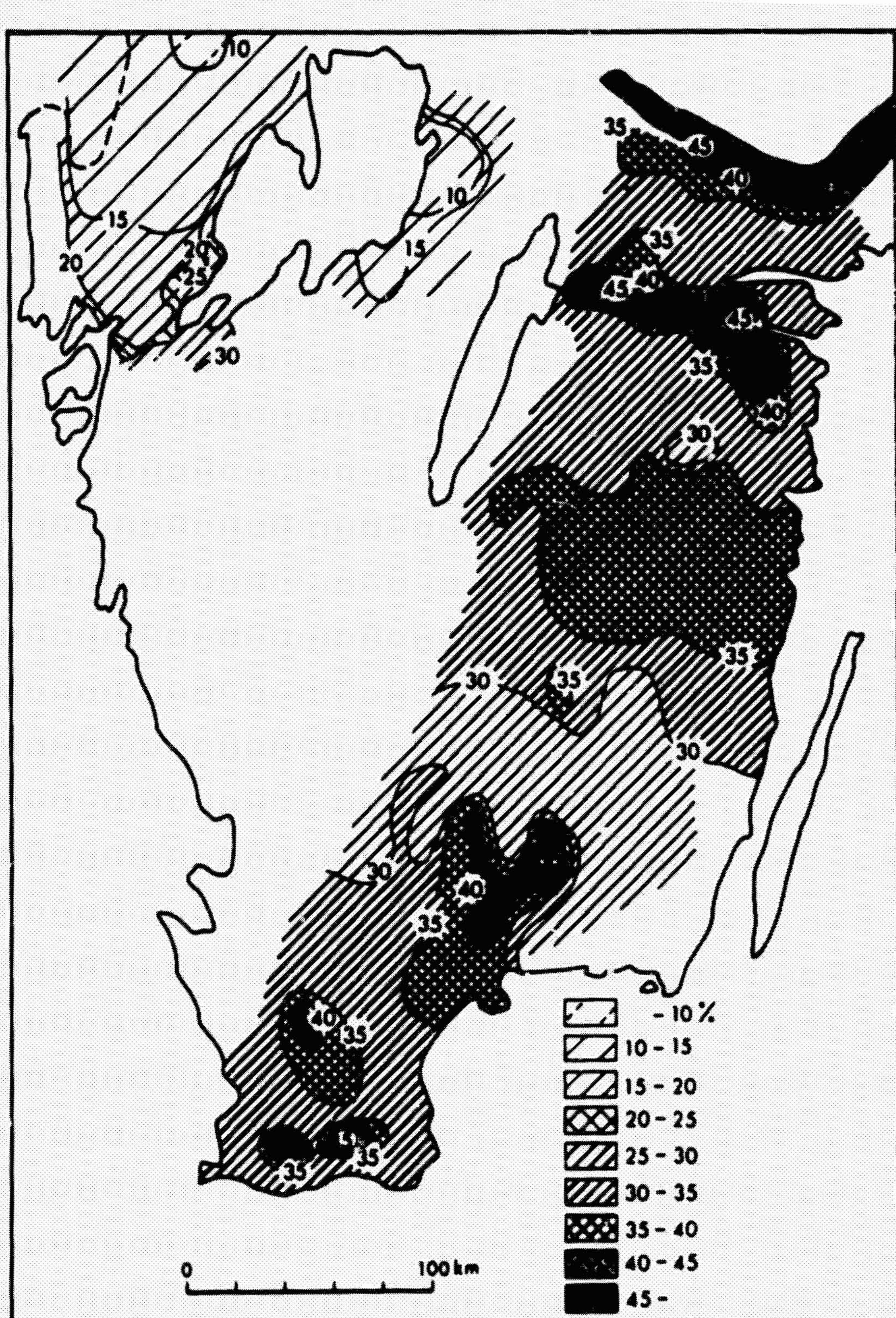


Figure 11.- Map of land areas with lakes of the same grey-tone class where the given figures represent transmission values gained after densitometer analysis of LANDSAT-1 images (MSS 4) registered on June 18 and July 3, 1973.

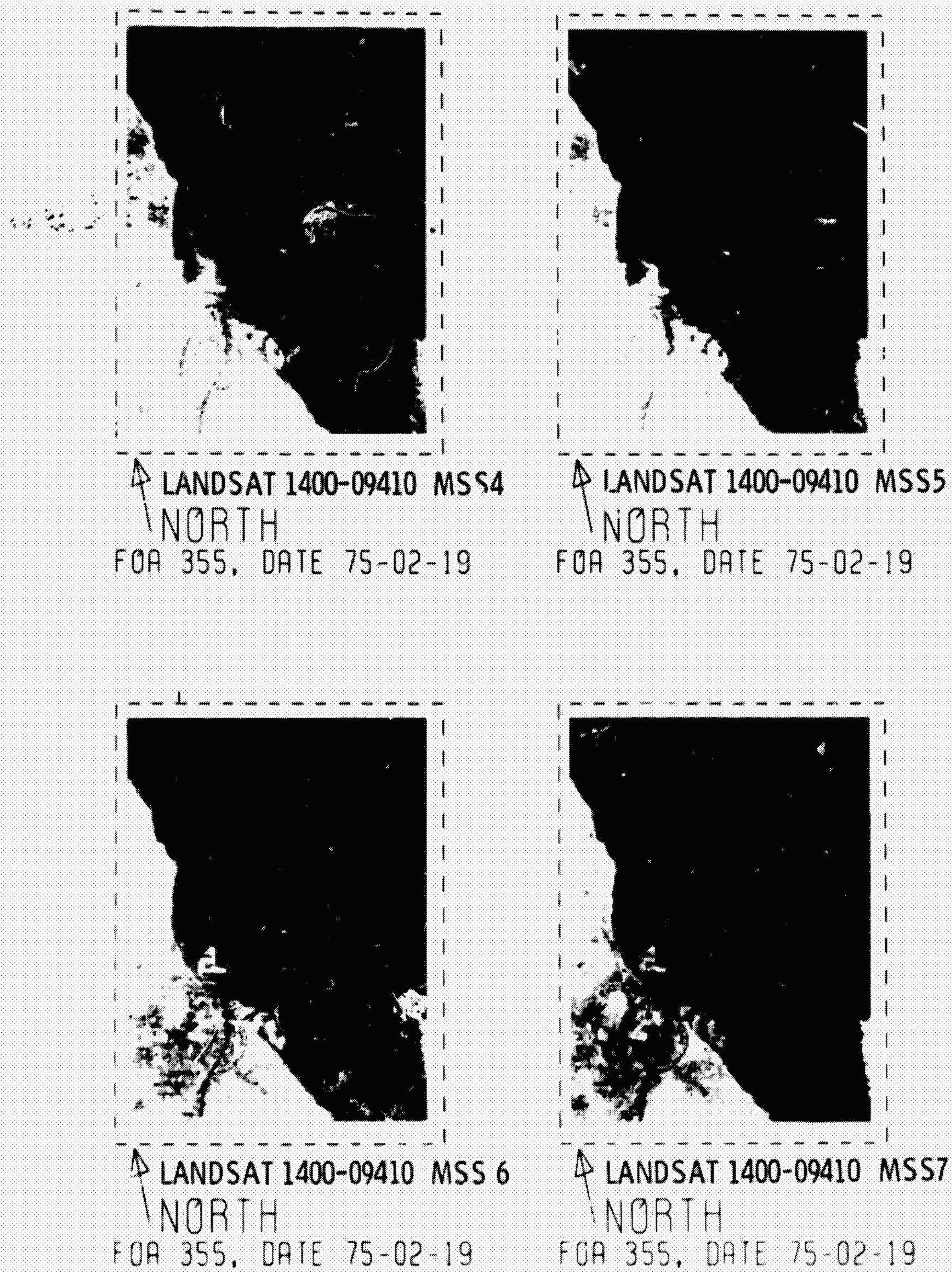


Figure 12.- The pollution conditions outside Copenhagen on August 27, 1973. The grey-tone differentiation of the water has been enhanced and the image has been produced with the help of a Calcomp 835 microfilm plotter. Appr. scale 1:250,000.

COMPARATIVE UTILITY OF LANDSAT-1 AND SKYLAB DATA FOR COASTAL WETLAND MAPPING AND ECOLOGICAL STUDIES

E-14

By Richard Anderson, Biology Department, The American University, Washington, D.C.
Linda Alsid, Biology Department, The American University, Washington, D.C.
Virginia Carter, U.S. Geological Survey, Reston, Virginia

N76-17498

ABSTRACT

There are a variety of remotely sensed data and analysis methods currently available for application to wetland mapping and ecological studies. The most widely used techniques involve color and color infrared photography from low altitude (1830 M) aircraft. These techniques, while giving a high degree of accuracy, are time consuming, expensive, and have to be used on a piecemeal long term basis by some states. Less expensive methods which retain relative accuracy and detail would be an attractive near term alternative. Skylab 190-A photography and LANDSAT-1 analog data have been analyzed to determine coastal wetland mapping potential as a near term substitute for aircraft data and a long term monitoring tool. The level of detail and accuracy of each was compared. Skylab data provides more accurate classification of wetland types, better delineation of freshwater marshes and more detailed analysis of drainage patterns. LANDSAT-1 analog data are useful for general classification, boundary definition and monitoring of human impact in wetlands.

INTRODUCTION

Wetlands, especially salt marshes, play a primary role in estuarine productivity, providing food and shelter not only for organisms naturally inhabiting the wetlands, but also for the many organisms which spend all or part of their lives in the waters of the adjacent estuary or shallow ocean. Salt marshes are vitally necessary to the maintenance of virtually all major shallow salt water fish and shellfish populations.

During the last five years a clear need has been established for development of a rapid, relatively low cost method for mapping and monitoring coastal wetlands. This period has been one of unprecedented activity by state governments to preserve this sensitive and threatened part of the aquatic ecosystem. Laws regulating the types of activity in wetlands have been passed in almost all Atlantic coastal states. To implement this wetland legislation, practical methods are needed for mapping and evaluation of coastal wetlands.

With the launch of LANDSAT-1 and Skylab, relatively high resolution satellite data became routinely available for the investigation of earth resources. The research described in this paper was initiated to determine the feasibility of using LANDSAT-1 and Skylab data for investigations of coastal wetland ecology and to monitor and map coastal wetlands.

Test Areas for LANDSAT-1 and Skylab Studies

Due to the wide range of environmental conditions along the Atlantic Coast, two test areas were selected for study; one representing northern type coastal wetlands in the

Chesapeake Bay, Maryland, and Chincoteague Bay, Virginia, and one representing southern type coastal wetlands in South Carolina and Georgia. Lack of usable Skylab data over the southern test area prevented comparison with LANDSAT data; therefore, only the northern area will be discussed.

Two sites were selected for intensive study. Site 1 is a large, near-saline marsh at the mouth of the Nanticoke River in Dorchester County, Maryland. Site 2 is a salt marsh complex located at the mouth of the Chincoteague Bay in Virginia. The tidal range is about 1 meter.

The frequently inundated saline and near-saline marshes in the Chesapeake Bay area contain many of the same species found in the southern marshes (i.e., *Spartina alterniflora*, *Spartina patens*, *Juncus roemerianus*, etc.). However, these species seldom grow to heights comparable to those achieved in southern marshes and consequently, estimates of their primary productivity are lower (Keefe and Boynton, 1972). This is probably because of a shorter growing season and generally cooler air and water temperatures.

METHODS AND MATERIALS FOR DATA ANALYSIS

A variety of methods for satellite data analysis were tested and evaluated. These include both visual and automated interpretation techniques. The authors are particularly indebted to the NASA aircraft support programs operated from Ames Research Center, California, and Johnson Space Flight Center, Texas, and the Wallops Research Station, Virginia. Underflight data have been invaluable as aids in interpretation of the satellite data.

Prior to and during the time of receipt of satellite data, aircraft color infrared photographs of the test site were visually analyzed to identify boundaries, plant communities and disturbed areas. Preliminary interpretations were made using LANDSAT-1 analog and Skylab photographic data. Field trips were made to determine accuracy of laboratory interpretation.

To facilitate interpretation of grey levels and color tones on the satellite data, a considerable amount of data were gathered on the spectral reflectance characteristics of important wetland features; an ISCO field Spectroradiometer was used to obtain this information at 0.025 micrometer intervals between 0.4 and 0.75 micrometers and at 0.050 intervals between 0.75 and 1.350 micrometers. Figure 1 shows seasonal reflectance curves for some wetland features keyed to LANDSAT MSS band 7 (0.8 - 1.1 micrometers). These data were also used in the development of techniques for analysis of LANDSAT digital data.

RESULTS

A. LANDSAT-1

1. Plant species identification and wetland classification.- MSS bands 6 and 7 were found to be the most useful for wetlands interpretation.

Coastal saline and brackish marshes generally appear as a dark grey tone near the dense end of the scale on LANDSAT MSS band 6 and 7 images, and as a dark red-grey in a color infrared simulation (color composite) during the growing season. This is largely because

the spectral reflectance of the dominant species, or species association, is generally low in MSS bands 6 and 7. These species include Spartina alterniflora (salt marsh cordgrass), Salicornia spp. (glasswort), and Juncus roemerianus (needlerush). In MSS bands 4 and 5, all marsh species have a low overall average reflectance, usually appearing less dark in tone than dryland vegetation and darker than spoil or agricultural fields with or without crops. Where the coastal marshes become fresher, the spectral reflectance of the species compositions is higher in the infrared region of the spectrum and the plant cover is generally denser. During the peak of the growing season, it is difficult to determine the landward boundaries of these fresh marshes.

The general vegetative composition of the test sites is typical of near-saline to slightly brackish tidal marshes of the Central Atlantic coast. The areal extent of plant communities range from small to very large.

A vegetation map (Figure 2) was produced from the 7 July 1973 MSS 7 (# 1349-15134) and the 30 August 1973 MSS 7 (# 1403-15124) images. Two different dates were used in order to evaluate the tidal differences. The imagery was placed in a Bessler enlarger and tonal patterns traced by hand. The general categories identified are listed in order of decreasing reflectivity: tree island, high marsh, low marsh, low marsh/water and water. The high marsh includes those plant species and communities which are generally found above mean high water. The vegetation is usually dense with little background reflectance and soil moisture. The high marsh category is more reflective and images lighter on MSS band 7 than other marsh categories. This category is made up of varying amounts of Spartina cynosuroides, Spartina patens/Distichlis spicata association, Iva frutescens, Baccharis halimifolia, and Phragmites communis.

Low marsh covers the greatest area within the test site, and is composed mostly of large stands of Juncus roemerianus. Other species of the low marsh category, Scirpus spp., may be found in homogeneous stands but are predominantly seen in large mixed plant communities. Juncus stands were indistinguishable from Scirpus stands or mixed Juncus and Scirpus communities.

Low marsh/water contains shorter Juncus and Scirpus stands, or areas with sparse plant cover which exhibit a very low reflectance in MSS band 7 due to the water background. In many instances it is impossible to determine the interior low marsh/water interface using satellite data.

High and low marsh patterns on the LANDSAT imagery are more distinct in summer than winter, due to the greater differences in reflectance of growing vegetation. Seasonal development or change within the high marsh category can be distinguished by comparing the spring and summer imagery. Increases in reflectance are especially noticeable in the areas bordering streams and water bodies of the marsh interior in MSS 7.

An attempt was made to determine the applicability of LANDSAT data for coastal wetland typing or classification. A wetland classification system based on satellite data would be useful for making and updating coastal inventories. Shaw & Fredine, 1956, suggested classification of coastal marshes into the following types on the basis of vegetation and inundation:

Type 12 - coastal shallow fresh marshes
Type 13 - coastal deep fresh marshes
Type 14 - coastal open fresh water
Type 15 - coastal salt flats
Type 16 - coastal salt meadows
Type 17 - irregularly flooded salt marshes
Type 18 - regularly flooded salt marshes
Type 19 - sounds and bays

Some of these categories can be differentiated using LANDSAT imagery. The differentiation is based largely on the reflectance differences of indicator species [e.g., Spartina alterniflora (Type 18), Juncus roemerianus (Type 17) or Spartina patens (Type 16)]. Although LANDSAT cannot be used to ascertain water depth, Type 14 and Type 19 which are based on water depth could be classified by using available bathymetric data in conjunction with areas of water detected with LANDSAT data. We have not successfully differentiated Type 12, 13, or 15 with LANDSAT images.

2. Monitoring of wetlands for natural or man-made reductions in productivity.- Natural reductions in productivity due to successional trends (e.g., wetland to dryland) must be ascertained over longer periods of time than this study permitted. Repetitive LANDSAT data will be particularly useful for this purpose.

The most useful short term use will be in monitoring dredge, fill and drainage activities in wetlands.

B. Skylab

Color infrared photography was found to be the best data form for wetland studies. Tonal contrast, expressed as variations of color, was found to be the most important recognition element in interpreting the color IR photographs. Texture, the frequency of color change, was also an important interpretive factor in certain areas. The September photography was superior to that taken in June for delineating the upper marsh boundary. The marsh-water interface, especially in small drainage channels, is also more easily identified in September because of reduced vegetation cover.

Tonal contrast and image sharpness within the marshes were of sufficient detail to allow delineation of five wetland classes. This was especially true of the June photography where certain individual species were easily identified by their characteristic colors.

To differentiate the wetland classes found in the test area, a wetlands classification system was developed. It is basically a synthesis of systems previously used by Nicholson and Van Deusen and Stewart modified by observations of marsh structure and composition in the field and the discrimination capability of the Skylab photography. The five major vegetation categories are:

Type I, Fresh estuarine river marsh.- Dominated by fresh water vegetation located along the upper reaches of tidal rivers and streams where water salinity ranges from fresh to slightly brackish, large areas of open water may be covered with Nymphaea odorata (white water lily). Broad leaf emergents, Pontederia cordata (pickerel weed), Peltandra virginica (arrow arum), and Nuphar advena (spatterdock), occupy the water edge. Shallower interior areas are characterized by a wide diversity of herbaceous vegetation which varies with area and season.

Because of the complex mixing of many diverse species within Type I wetlands, the appearance on the photography is one of homogeneity, with little internal tone contrast and a uniform texture. However, large, nearly pure stands of Phragmites communis (reed) and Typha spp. (cattail) occur and have been identified using the June photography. Phragmites is characterized by a bright pink color and rosette pattern; Typha spp. appear in the deepest shade of red. Nymphaea odorata, which exhibits a white tone and obscures the water surface, can also be discerned.

Type II, Brackish estuarine river marsh.- As salinity increases downstream, the Type I wetlands are gradually replaced by plant communities more tolerant of brackish

water. Tidal fluctuation is regular and usually greater toward the river mouth. The marsh area may be large and heavily dissected by drainage creeks. This is perhaps the most complex category and most difficult to define. Many of the fresh water species listed as Type I vegetation extend into the brackish areas, and there is no distinct boundary between the two types. Typically, broad leaf emergents at the water edge are replaced by Spartina cynosuroides (big cordgrass), which also occurs in large stands in the interior marsh. Other brackish dominants include Scirpus olneyi (Olney three-square), Typha angustifolia (narrow-leaf cattail), Spartina patens (salt meadow cordgrass), and Distichlis spicata (saltgrass).

Type III, Fresh estuarine bay marsh.- Estuarine systems such as the upper Blackwater River may flow through a broad, shallow, permanently submerged flats. Salinity ranges from slightly to moderately brackish and tidal fluctuation is usually slight and irregular.

Scirpus olneyi, occurring in large pure stands, dominates this class in the test area. A mixture of Scirpus olneyi and Typha angustifolia is found in fresher water areas, and a zone of Panicum virgatum or Spartina patens occupies higher elevations at the upper marsh boundary.

Because of the complete dominance of Scirpus olneyi, this category appears as a rather homogeneous area on both the June and September photography. Large, shallow, irregular ponds and sparsely-vegetated mudflats in combination with the low reflectance of Scirpus olneyi make this the most difficult area in which to delineate accurately the marsh-water interface.

Type IV, Brackish estuarine bay marsh.- This class differs vegetationally from Type III because of higher water salinity. Scirpus olneyi, Juncus roemerianus (needlerush), and Spartina patens provide the dominant vegetative cover. Scirpus olneyi is found in low, poorly drained areas; Juncus roemerianus becomes established in low areas with sandy soils; and Spartina patens occupies higher elevations. Spartina alterniflora is common where tidal fluctuation is the most regular, and homogeneous stands of Typha spp. are often found along the upper marsh boundary. This marsh class exhibited the greatest variations of color of all classes, and had a distinctive texture.

Type V, Near saline marsh.- This class occurs near the open water of Chesapeake Bay. The water is moderately brackish to near-saline and species diversity is reduced. The marsh pattern is formed by extensive, pure stands of Juncus roemerianus and large meadows composed of Spartina patens and Distichlis spicata. At the highest elevations, patches of Iva frutescens and Baccharis halimifolia are found, and Spartina alterniflora occupies the narrow intertidal zone along creeks and streams.

Wetland maps were prepared at a 1:125,000 scale by making a direct overlay on the S190A enlarged color IR transparencies (June and September). The wetland maps depict the five categories as well as the boundary between marsh and upland or marsh and wooded swamp (upper marsh boundary) and the marsh-water interface (Figs. 2 and 3).

2. Monitoring natural and man-made reductions in primary productivity: Skylab is basically not a monitoring tool due to the short term duration of the missions. Due to the higher resolution of Skylab photography, dredge and fill projects of less than one acre may be observed. Also mosquito ditches are resolved and vegetational changes which accompany them.

DISCUSSION AND CONCLUSIONS

Wetland mapping and monitoring presents both a near and a long term problem. Maps showing boundaries and classes of wetlands are urgently needed by many states as baseline

information to begin management and preservation programs. Longer term, repetitive data are also necessary for monitoring of reductions in wetland acreage due to human activities or natural successional processes. High resolution, photographic data from Skylab provides the best information for detailed wetland mapping. LANDSAT analog data have been shown to be an excellent tool for mapping large area coastal wetland communities and monitoring changes in wetland habitat, particularly those associated with human activities.

Wetland maps produced from LANDSAT analog and Skylab 190-A photographic data of the Nanticoke test site were compared (see Fig. 2). The following generalizations apply:

1. With regard to classification, a more detailed system may be used with Skylab data (5 classes as opposed to 3 for LANDSAT).

2. Freshwater marshes may be delineated with Skylab but not LANDSAT.

3. Drainage patterns may be mapped in more detail with Skylab.

REFERENCES

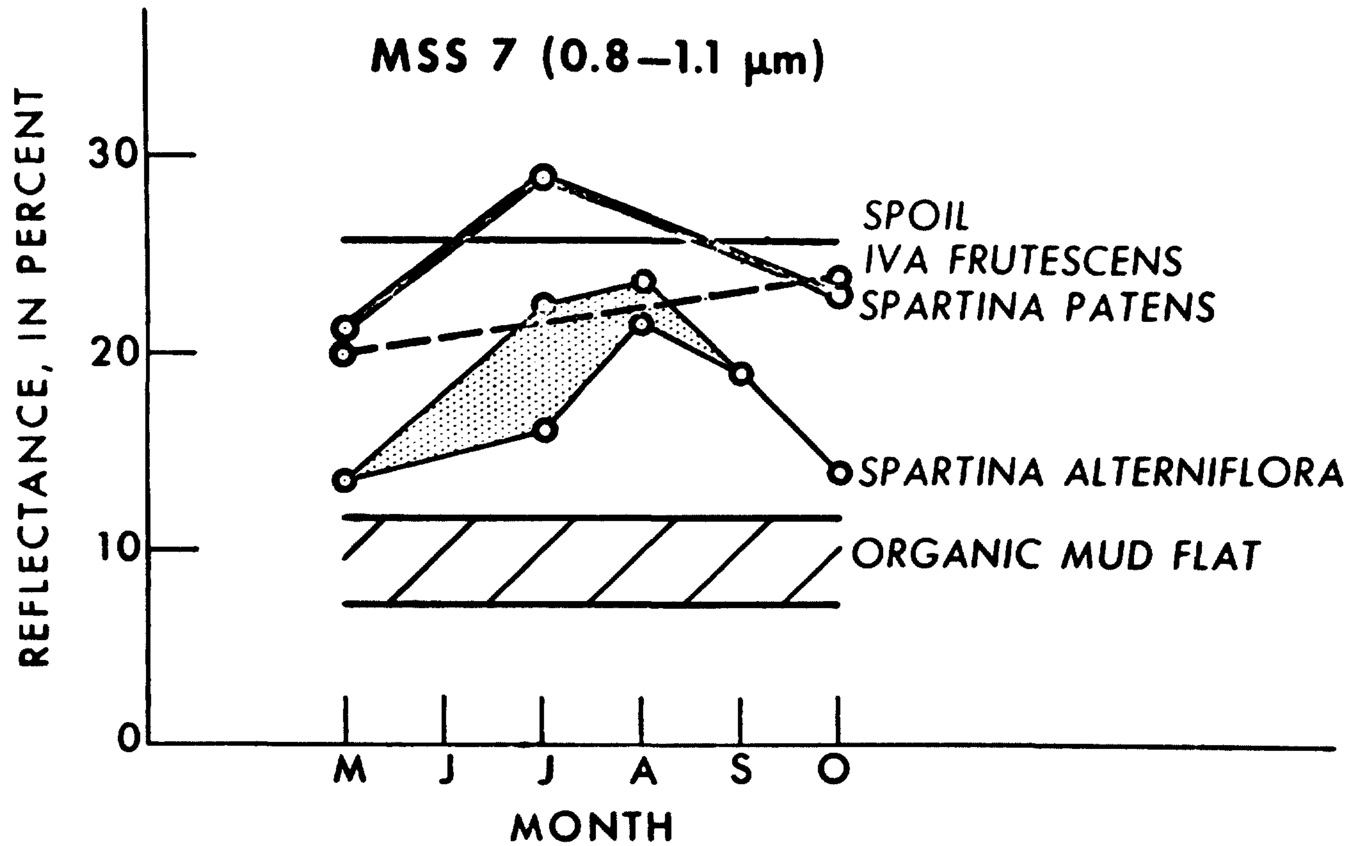
Anderson, R. R., V. Carter and J. W. McGinness. 1973. "Mapping Atlantic coastal marshlands, Maryland-Georgia, using ERTS-1 imagery." In: Symposium on Significant Results Obtained from the Earth Resources Technology Satellite 1, Vol. 1: Technical Presentations, Sec. A, p. 603-614.

Anderson, R. R. and F. V. Wobber. 1973. "Wetlands mapping in New Jersey." Photogrammetric Engineering 39(4):353-358.

Keefe, C. W., and Boynton, W. R. 1972. "Standing crop of salt marshes surrounding Chincoteague Bay, Maryland-Virginia, Chesapeake Science, v. 14, no. 2, p. 117-123.

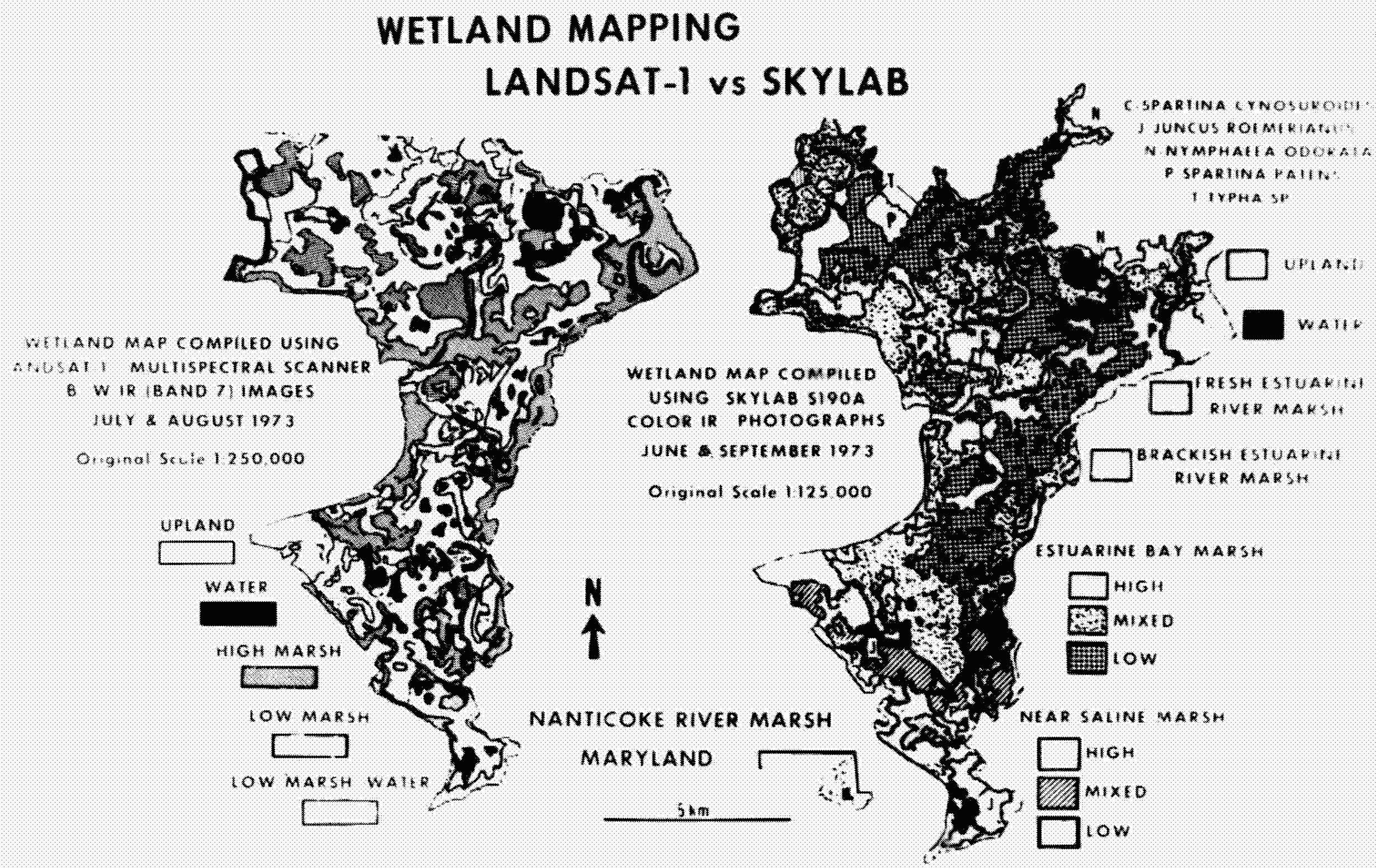
Nicholson, W. R., and Van Deusen, R. D. 1944. "Maryland marshes: job completion report." Pittman-Robertson Inv. Proj. no. W-30-R1, 10 p.

Shaw, S. P. and C. G. Fredine. 1956. "Wetlands of the United States: Their extent and their value to waterfowl and other wildlife." Circular 39, Fish and Wildlife Service, U.S. Department of Interior, U.S. Government Printing Office, Washington, D.C., 67 p.



REFLECTANCE OF WETLAND CLASSES—MSS 7

Figure 1



WETLAND MAPPING
LANDSAT-1 vs SKYLAB
WETLAND MAP COMPILED USING
MULTISPECTRAL SCANNER
B W IR (BAND 7) IMAGES
JULY & AUGUST 1973
Original Scale 1:250,000
UPLAND
WATER
HIGH MARSH
LOW MARSH
LOW MARSH WATER
WETLAND MAP COMPILED
USING SKYLAB S190A
COLOR IR PHOTOGRAPHS
JUNE & SEPTEMBER 1973
Original Scale 1:125,000
N
NANTICOKE RIVER MARSH
MARYLAND
5km
J JUNCUS ROEMERIANUS
N NYMPHAEA ODORATA
P SPARTINA PATENS
T TYPHA SP
UPLAND
WATER
FRESH ESTUARINE
RIVER MARSH
BRACKISH ESTUARINE
RIVER MARSH
ESTUARINE BAY MARSH
HIGH
MIXED
LOW
NEAR SALINE MARSH
HIGH
MIXED
LOW

Figure 2

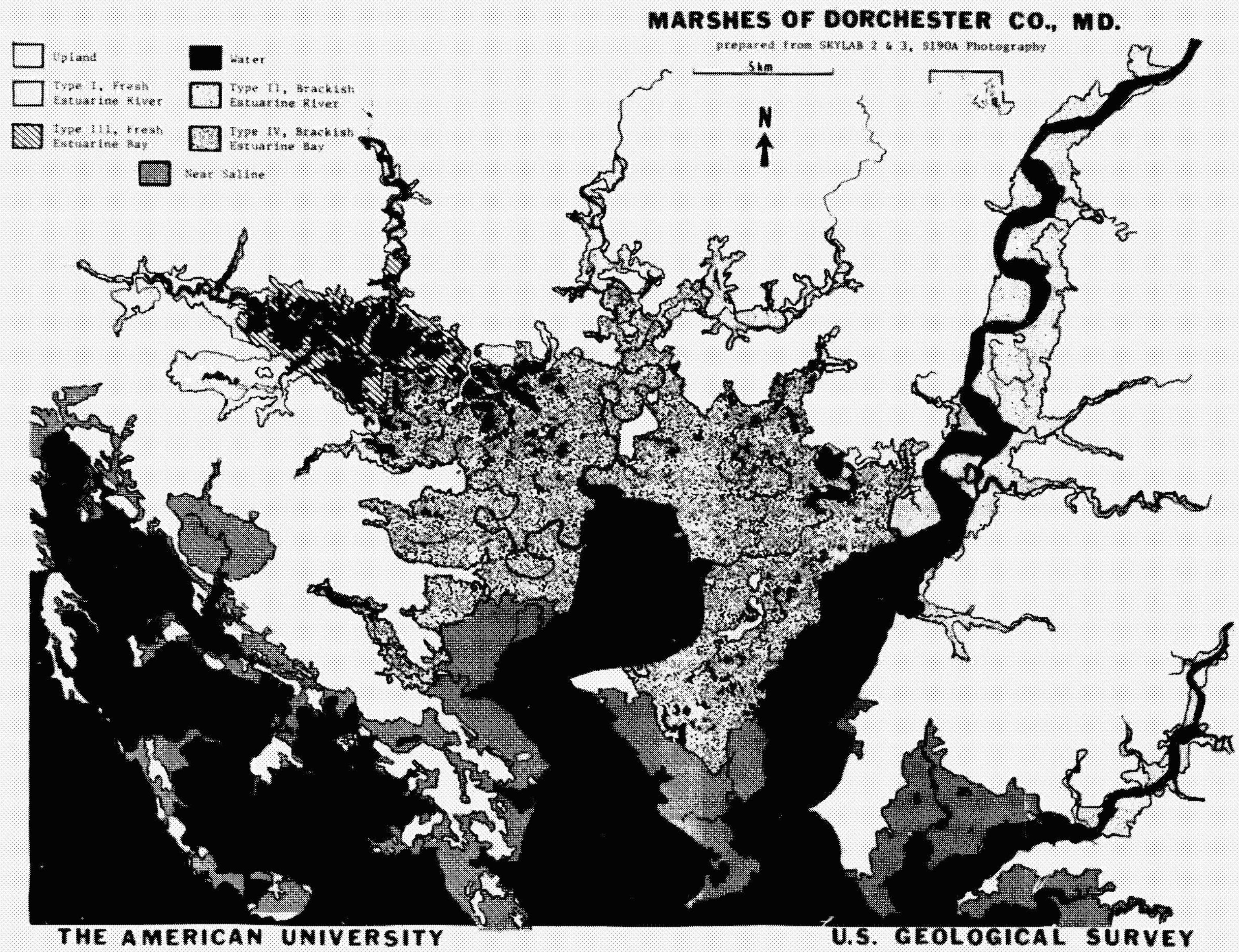

MARSHES OF DORCHESTER CO., MD.
prepared from SKYLAB 2 & 3, S190A Photography
5km
N
Upland
Water
Type I, Fresh Estuarine River
Type II, Brackish Estuarine River
Type III, Fresh Estuarine Bay
Type IV, Brackish Estuarine Bay
Near Saline
THE AMERICAN UNIVERSITY
U.S. GEOLOGICAL SURVEY

Figure 3

AUTOMATIC CATEGORIZATION OF LAND-WATER COVER TYPES OF THE GREEN SWAMP, FLORIDA, USING SKYLAB MULTISPECTRAL SCANNER (S-192) DATA

E-15

A. E. Coker*, A. L. Higer**,
R. H. Rogers***, N. J. Shah***, L. Reed***, and S. Walker***

N76-17499

ABSTRACT

The Green Swamp, the fountainhead of five major rivers, a broad flat wetland comprising 2,253 square kilometers (870 square miles) of the central highlands of the Florida peninsula was chosen as a Skylab Earth Resources Experiment Package (EREP) test site. This report summarizes the techniques used and the results achieved in the successful application of Skylab Multispectral Scanner (EREP S-192) high-density digital tape data for the automatic categorizing and mapping of land-water cover types in the Green Swamp. Data was provided from NASA Skylab pass number 10 on 13 June 1973. Significant results achieved included the automatic mapping of a nine-category and a three-category land-water cover map of the Green Swamp. The land-water cover map was used to make interpretations of a hydro-logic condition in the Green Swamp. This type of use marks a significant breakthrough in the processing and utilization of EREP S-192 data.

INTRODUCTION

There are encroaching pressures of urban and industrial development in the environmentally sensitive area of the Green Swamp. This area, essential to water resources and the ecological stability of major drainage systems, is a complex of swamps, creeks, rivers, lakes, prairies, pine flatwoods, and sand hills. The water, land, and vegetation are undergoing rapid changes caused by logging, reforestation, alteration of natural drainage by canalization and ponding, burning and clearing for sod farming, improved pasture, citrus

*U. S. Geological Survey; Water Resources Division; Tampa, Florida

**U. S. Geological Survey; Water Resources Division; Miami, Florida

***Bendix Aerospace Systems Division; Ann Arbor, Michigan

farming, and urban and industrial development. There is an urgent need for environmental appraisals in this area to develop a rational basis for planning and controlled development. Conventional techniques, based primarily on the use of photography and field studies, have not been entirely satisfactory for this timely appraisal because of the large size and complexity of the area. In response to these deficiencies, this study objective is to use the Green Swamp and its environs as a laboratory to evaluate Skylab multispectral scanner data for automatic mapping of the needed environmental categories for interpretation and assessments.* A timely use of remote sensing data resulting from this study has already been demonstrated by the Green Swamp settlement (Ref 1).

LOCATION AND DESCRIPTION OF THE GREEN SWAMP TEST SITE

The Green Swamp is in the central part of the Florida Peninsula, as shown in Figure 1. The swamp is an extensive area of swampy flatlands and sandy ridges. The elevation of the land surface varies from about 60 meters (200 feet) above mean sea level in the eastern part to about 23 meters (75 feet) in the western part. Five major drainage systems originate in or near the Green Swamp area, as shown in Figure 2. The Withlacoochee River drains two-thirds of the area. The little Withlacoochee River, the headwaters of the Oklawaha River, the Hillsborough River, the headwaters of the Kissimee River, and the headwaters of the Peace River drain the remaining area.

The Green Swamp was described by Pride (Ref 2) to include the southern parts of Lake and Sumpter Counties, the northern part of Polk County, and the eastern parts of Pasco and Hernando Counties, as shown in Figure 2. The eastern boundary is U.S. Highway 27, from Clermont south-southeastward to Haines City. The southern boundaries generally coincide with divides separating drainage northward to the Withlacoochee River basin from drainage southward to the Peace and Hillsborough River basins. The western

---

*This report is based on work initiated in April of 1973 by the U.S. Geological Survey and performed under NASA Skylab EREP Contract CC-30280A, EREP Proposal Number 448.

boundary is U.S. Highway 301, northward from Dade City to St. Catherine. The northern boundary extends from St. Catherine eastward to, and along, State Highway 50 eastward to Clermont. The boundaries described enclose an area of approximately 2,253 square kilometers (870 square miles).

The Green Swamp is not a continuous expanse of swamp but a composite of many swamps that are distributed fairly uniformly within the area. Interspersed among the swamps are low ridges, hills, and flatlands. Several large and many small lakes of sinkhole origin rim the southeastern and northeastern parts of the area. Prominent topographic features affecting the drainage of the eastern part of the area are the alternating low ridges and swales. These features trend generally north-northwestward and are parallel to the major axis of the Florida peninsula. In the western part of the area, the main land-surface features are large swamps, flatlands, and rolling hills. Most of the swamps support good growths of cypress trees. In the flatlands and uplands, pine and scrub oak trees grow abundantly. The largest continuous expanse of swampland lies within the valley of the Withlacoochee River.

The Green Swamp area has a warm humid climate. The average summer temperature is 27°C (81°F) and the average winter temperature is 16°C (61°F). About 75% of the 135 centimeters (53 inches) of rainfall per year that reaches the land surface in the Green Swamp area is lost to evapotranspiration. The remaining 25% recharges the underlying aquifers and replenishes swamps, streams, lakes and ponds. Because of the gradual slope of the land and the dense vegetative cover, the river basin systems drain surface waters from the Green Swamp area very slowly. As a result of this slow drainage process, surface waters remain within the area for extended periods following the rainy season.

The surface is mantled with a varying thickness of sand and clay which comprises the nonartesian aquifer. Underlying this mantle is an intermediate unit of sandy clays and interbedded limestone layers that, where present, may form a semi-confining layer above porous marine limestones that underlie and drain the subsurface.

The vegetative associations and soil types in the Green Swamp area can best be organized into three major categories; wetlands, flatwoods, and uplands.

Wetland plants and soils occur in low wet areas which may be inundated for varying portions of the year and, in the past, have rarely, if ever, been burned by forest fires. The soils in these areas are usually poorly drained and high in organic matter and often have clayey subsoils. The wetland vegetative associations within the Green Swamp area are river and creek floodplains, cypress heads, bayheads, sloughs, and freshwater marshes.

The flatwoods vegetative associations occur on low nearly-level areas with sandy strongly-acid soils and a high water table. Periodic inundation and saturation during the wet season and the occurrence of fire during certain dry seasons have molded vegetative associations which are adapted to these stresses. These associations, known as pine flatwoods, have three species of pine as the predominant overstory; longleaf pine, slash pine, and pond pine. The agricultural modifications range in intensity from rangeland, where much of the pine overstory and palmetto understory remain, to improved pasture.

The majority of the upland soils are well-drained to excessively-drained deep sandy soils that are low in organic matter, strongly acid, and low in fertility. The natural vegetative associations found on these soils are the sandhill communities, with longleaf pine and various scrub oak species, and hammocks, with live oak and laurel oak. Much of these areas in the eastern and southeastern portions of the Green Swamp have been developed as citrus groves.

Because of the abundance of natural food, water, and shelter, a wide variety of wildlife populations are found within the Green Swamp. The swamp also serves as a wintering ground and migratory stop-over for many birds that breed elsewhere in North America. Endangered or threatened species within the area include the American alligator, bald eagle, osprey, and Florida panther.

PROBLEM

The Green Swamp area is undergoing rapid change caused by logging, reforestation; alteration of natural drainage by canalization and ponding; burning and clearing for sod farming, improved pasture, citrus farming, and urban and industrial development. Citrus production and related

industrial processing occurs in adjacent Polk County, the sixth largest producer of citrus products in the world. There are some sand-mining operations scattered throughout the Green Swamp. Phosphate mining in nearby Polk County produces 24 percent of the world's phosphate supply.

The pressure for further development in the Green Swamp is mounting daily as a result of its location between three of the fastest-growing areas in the state. The 1980 population estimate for the Orlando tri-county area is 740,100 and for the Tampa-Hillsborough area is 629,500, a population increase of 63 to 28 percent, respectively, for the ten-year period from 1970 to 1980.

The establishment of the Disneyworld complex, located on 111 square kilometers (27,443 acres) about 8 kilometers (five miles) east of the Green Swamp, has had the greatest impact on the alteration of land use, economy, and population growth in central Florida. Since 1967, there has been more than 300 square kilometers (75,000 acres) of agriculture and open land purchased for development in the Disney area between Orlando and the Green Swamp. These developments are primarily tourist and residential-oriented. Major tourists attractions recently completed include Sea World and Circus World. The largest residential development underway is Poinciana, a 194 square kilometer (48,000 acre) development with a projected population of 250,000.

National, state, and local government agencies, as well as conservationists, environmentalists, and private citizens, are becoming increasingly alarmed over the potential loss of the Green Swamp to urbanization. It is now realized that improper planning and construction of new industrial and residential areas in the Green Swamp can have a disastrous effect on this environmentally-sensitive area. In this area, there is an urgent need for environmental appraisals to develop a rational basis for planning and controlled development. The timely acquisition and production of maps and data needed for this appraisal; based on the use of conventional aerial photography, photometric mapmaking, and field studies; has not been satisfactory because of the large size and complexity of the Green Swamp.

OBJECTIVES

In response to the need for a timely and economical means of acquiring the information needed for the environmental appraisal of the Green Swamp, this investigation is to evaluate the suitability of using Skylab S-192 data as a basis for acquiring the needed environmental information. To accomplish this program objective, the Green Swamp was used as a laboratory, representative of many similar environmentally sensitive areas throughout the world. Intermediate goals that were accomplished in achieving this objective included:

- Developing techniques for processing and analyzing Skylab S-192 high-density digital tapes.

- Evaluating relative spectral contributions of S-192 bands and comparing with ERTS band to delineate land-water cover categories in the Green Swamp.

- Evaluating application of automatically-categorized imagery for use in the environmental analysis of the Green Swamp.

Achieving these objectives would not only contribute to the much-needed environmental survey of the Green Swamp, but would provide the tools and techniques needed to perform similar surveys worldwide.

DATA PROCESSING

The objectives of this investigation were achieved through development and application of computer processing techniques for automatic categorization of land-water cover types from S-192 data.

Figure 3 shows the elements of the Bendix Earth Resources Data Center used to transform the high density digital tapes (HDDT) into computer compatible tapes (CCTs) and image products. The elements of this center include a Digital Equipment Corporation PDP-11/15 computer with 32 K-words of core memory, two 1.5 M-word disk packs, two nine-track 800-bit-per-inch tape transports, a high-speed processor, a linc printer, a card reader, and the teletypewriter unit. Other units are the color moving-window computer-refreshed display, operator console, a glow-modulator film recorder, and a Gerber plotter.

The steps used in the processing and analysis of the S-192 data are shown in Figure 4. The steps, as noted in the figure, are grouped into three phases; pre-processing, analysis, and processing. The pre-processing phase includes those works necessary to transform the S-192 HDDT into a noise-filtered linearized tape, recorded in a standard computer-tape format. This phase also includes the generation of single-band and false-color imagery to support the analysis of S-192 noise and the location and selection of land-water category training areas.

The analysis phase includes locating training areas representative of each land-water category and the development and evaluation of the spectral characteristics and computer processing coefficients for each category. This phase is repeated until an acceptable categorization accuracy is achieved. The output of the analysis phase is the processing coefficients which are then used by the computer to generate nine and three-category color-coded land-water cover maps of the test site.

The implementation of the processing phases and the results achieved are briefly summarized in the following paragraphs.

Pre-Processing Phase

Generate raw data. The 13 bands of S-192 data were provided by NASA as a bi-phase modulated digital signal on fourteen-track magnetic tape with a 10,000 bit-per-inch (bpi) packing density. Two bands are multiplexed onto one track of the tape.

The first processing objectives were to locate the HDDT coordinates of the data acquired on the Green Swamp test site and to transform this data to a standard CCT format. Coordinate location was established by viewing the HDDT data on the TV monitor, as shown in Figure 3, and by generating and analyzing 70-mm film of the taped data.

This imagery, although badly distorted geometrically because of the conical scan pattern, permitted the start and stop scan lines bracketing the test site to be determined. The desired S-192 data were then transformed from the HDDT to a standard CCT format having nine tracks with 800-bpi records in ASCII code.

Generate linearized CCT. - Imagery produced from this raw data CCT and the HDDT contains the conical-line scan-pattern used by the S-192. During the early phases of the study, an attempt was made to locate known targets, using the TV monitor and gray-scale printouts where the data contained the conical pattern. Identification of most targets was found to be extremely difficult when the pattern was present. To improve the geometric fidelity of the S-192 data, a CCT whose data is "linearized" was generated from the raw data tape. On this tape, the data were recorded as if the S-192 scans were normal to the direction of spacecraft motion. For this approach, a straight line, normal to the spacecraft heading, was assumed. A nearest-neighbor processing algorithm was used to locate and record on the linearized CCT the picture elements or pixels that best correspond to this line. A total of 265 conical scan lines contributed pixels to the 916-pixel normal or linearized line. Each pixel on the linearized line represents a ground coverage of approximately 79 by 79 meters (260 by 260 ft or 1.676 acres). The line length or swath width covers 72.4 kilometers (39.1 n. miles). Although the data resulting from this processing step are geometrically very good, some residual distortions remain, such as one resulting from earth rotation effects. To date, the removal of residual errors from the data has not been considered by this study.

Generate linearized imagery. - Imagery was produced from the linearized CCTs to support studies of noise in the S-192 bands and to aid in locating known ground truth areas. The production of film imagery at this intermediate stage was not an essential task, but a supportive one, since all bands and combinations of bands could also be viewed on the color TV monitor.

Figure 5 shows a 72.4 by 100 kilometer (39.1 by 54.0 n. mile) area of Florida in each of the 13 S-192 bands. Atmospheric parameters and noise factors degrade the quality of the imagery to some degree. A study of these factors has revealed the following information:

Atmospheric effects: In Band 1, low atmospheric transmission and backscatter of the sunlight from the atmosphere (path radiance) reduce the contrast of the scene.

Detector noise: A very low frequency (f) 1/f noise is very apparent in thermal Band 13.

Cooler piston noise: This noise is most noticeable in Band 5. The noise has a fundamental frequency in the range of 16 to 18 Hz (a period of about six scan lines).

Power inverter noise: This noise produces a herringbone pattern, has a fundamental frequency of 22.413 kHz, and is most noticeable in Band 4. The noise is also observed in Bands 1, 2, 3, 5, 7, and 8.

Sync drop-outs: This noise is most noted near the center of the image in Bands 11 and 12. Poor signal-to-noise ratio on the HDDT sync signal causes CCT generation to skip the video areas. This is most easily observed in Bands 11 and 12.

Fast Fourier transform (FFT) techniques are being used to determine exact noise frequencies. Digital simulation of notch filters and other techniques are being developed and applied to data to filter some noise frequencies.

Figure 6 shows a side-by-side comparison of false color composite images using three S-192 bands. The image on the right side in the figure was produced using S-192 Bands 4, 5, and 8. As noted in Table I, these bands correspond approximately to LANDSAT MSS Bands 4, 5, and 7. The false color image on the left side of the figure was generated from S-192 Bands 3, 6, and 11. It is significant to note that this spectral combination produced imagery of the test site which was far superior to that available with the ERTS bands. Band 11, as will be noted later, contributed more than any other band to the automatic categorization of the Green Swamp land-water cover types.

Analysis

Land-water cover types that represent environment categories for the interpretation and appraisal of environmental conditions in the Green Swamp were established on the basis of combining field studies with analysis of S-192 data. The initial objective was to automate the categorization of wetland, pine flatwood, and uplands with a categorization accuracy which would, as a minimum, satisfy Anderson's first criterion (Ref 3) of 90 percent or more.

Locate training areas. - The first task was to locate and designate to the computer a number of S-192 picture elements or pixels that best typified the land-water categories of interest, the "training areas". These areas of known characteristics were established from aerial photographs and ground survey data and were located on the S-192 CCTs by viewing the taped data on the TV monitor. The coordinates of the training areas were designated to the computer by placing a rectangular cursor over the desired area and assigning a training area designation, category code, and color code. Several training areas were picked for each category. The color code is used in later playback of the tapes when the computer-categorized data is displayed in the designated colors.

Develop processing coefficients. - The S-192 spectral measurements within the training area boundaries were edited by the computer from the CCT and processed to obtain a numerical descriptor to represent the "spectral characteristics" (computer processing coefficients) of each land-water category. The descriptors included the mean signal and standard deviation for each S-192 band and the covariance matrix taken above the origin. These descriptors were then used to generate a set of "canonical coefficients". This program, previously reported by Dye (Ref 4), derives, for each category, a set of canonical coefficients. In the automatic categorization processing, these coefficients are used by the computer to form a linear combination of the S-192 measurements to produce a "canonical variable" whose amplitude is associated with the probability of the unknown measurement being from the target sought.

In categorization processing, the probability of an S-192 pixel arising from each one of the different land-water categories of interest is computed for each pixel and a decision, based on these computations, is reached. If all probabilities are below a threshold level specified by the operator, the computer is permitted to decide that the category viewed is unknown, "uncategorized".

Evaluate selection of training areas and processing coefficients. - Before producing categorized data on a large amount of S-192 data, a number of tests were applied to evaluate the computer's capability of performing the desired interpretation. The tests include generating categorization accuracy tables similar to those shown in Table II and viewing the processed results on the TV monitor.

Selection of training areas, generation of accuracy tables, and evaluation of processing results using computer printouts and the TV monitor were iterative operations. To obtain accurate categorization of wetlands, pine flatwoods, and uplands, nine subcategories with corresponding training areas were established and then merged in the computer to define the three major categories. As noted in the accuracy table, Table II, the wetland category is composed of subcategories; cypress, water, fresh water marsh, bayheads, and mixed wetlands. The pine flatwoods category is composed of improved pasture, mixed palmetto, and pine. The upland category is composed of citrus. A number of training areas were picked for each subcategory to obtain a representative spectral representation for the composite.

The computer categorization accuracy achieved on the subcategories were established by analysis of the accuracy tables and by viewing the computer decisions which were displayed as color codes on the TV monitor. Table II indicates that all categories were correctly categorized over 86 percent of the time. It is also noted in the table that a small percentage of wetlands will be categorized as pine flatwoods but not visa versa. It is also observed that there is no confusion between pine flatwoods and uplands. The computer decisions were also displayed on the TV monitor, verified with ground-truth data, and found to be truly representative of land-cover conditions in the Green Swamp area.

Good ground truth was found to be essential for locating training areas and verifying categorization accuracy. We used LANDSAT-1 imagery, Skylab and U-2 photography, imagery from light aircraft and helicopters, and data from field-trips by jeep. The best ground truth data were found to be photographically acquired by Skylab, U-2, and helicopter surveys.

Band Contribution Factors. - One of the by-products of the canonical analysis program (Ref 5) is a figure of merit that specifies the relative importance of each S-192 band, i.e., its contribution, to separating each category from all other categories. Figure 7 shows, graphically, the importance of each band for all land-water categories considered in the Green Swamp study. Band 11 contributed most in categorizing all cover types in the Green Swamp except pine. In categorizing pine, Band 8 was most significant. Band 8 was the second most important band, when considered over all categories, with Bands 13 and 7 sharing the role of third most important band.

Processing

When satisfaction with the categorization accuracy was achieved on the nine subcategories, the processing coefficients were placed into the computer disk file and used to process that portion of the CCT covering the Green Swamp, approximately 1,562 scan lines. This first step in the categorization processing resulted in new or categorized CCTs, where each S-192 pixel is represented by a code designating one of the nine subcategories. This tape was later used to generate three and nine-category imagery, and as a medium to store the interpreted information on the study areas. Computer-generated area measurement tables were also edited from this tape to determine the areal extent of each category.

Area Measurement Table - The area measurement table, Table III, is the first real data product useful to land-use planning. This table provides a quantitative measure of the amount of land that falls within a particular category in terms of square kilometers, acres, and percent of the total area processed.

A review of the area printout shows that the wetlands category covers 29.76 percent (2,398.2 square kilometers) of the Green Swamp test area. The remainder of the area is approximately equally divided between pine flatwoods and uplands. The single most dominant subcategories are citrus (2,158.9 square kilometers), mixed palmetto (1,824.6 square kilometers), and cypress heads (1,318.6 square kilometers).

Obtaining similar area coverage tables from additional overflights on the test area would permit the environmental changes of the land to be determined.

Categorized Imagery - The categorized tape was also used to generate three-category and nine-category color-coded imagery of the Green Swamp, in which a color denotes a specific land-water category.

The categories and corresponding colors used in the nine-category imagery follows. The code following the color relates the category to those defined by USGS Circular 671 (Ref 6).

WETLANDS 05, 06

- BLUE, 05-01, 02, 03. Water, lakes, ponds, and streams.

- LIGHT BLUE, 06-01, 02. Fresh water marshes and bogs.

- TURQUOISE, 06-01, 02. Bayheads, marshes, and bogs.

- LIGHT GREEN, 06-01; 05-01. Cypress heads and sloughs.

- PURPLE, 06-01. Mixed wetlands, bayheads, bogs, and creek flood plains with mixed hardwoods and palms.

PINE FLATWOODS 03, 02

- GREEN, 03-01, 02; 02-01. Mixed palmetto, and natural rangeland.

- DARK GREEN, 02-01; 03-01, 02. Improved pasture, managed rangeland, and sod farms.

- YELLOW, 04-02. Pine, managed and reforested.

UPLANDS 02, 07, 01, (02, 03, 05, 06)

- ORANGE, 02-01, 02; 07-03; 01-01, 04, 05. Citrus, sandhills, extractive earth (gravel pits, construction sites, and other areas of disturbed or bare earth) residential, and transportation.

UNCLASSIFIED

- BLACK. This category includes all targets that do not exceed the probability thresholds established by the investigator.

Figure 8 shows the nine-category image together with ground-truth photographs of typical training areas representative of the wetlands, pine flatwood, and uplands. The central portion of the Green Swamp is observed in the categorized image to be comprised mainly by the colors blue, light blue, turquoise, light green, purple, green, and dark green, representing the wetlands and pine flatwood categories. The borders are predominantly orange. To the north and west, the north-northwestern trending ridges are observed as strips of orange, alternating with blues and greens to the east.

From analysis of the categorized imagery, the Green Swamp is a wetlands and pine flatwood basin, bordered at the northwest and west by uplands. The southwestern boundary is mainly a mixture of uplands and pine flatwoods that grades into a series of alternating north-northwestward-trending upland ridges and pine flatwoods, and wetland swales to the east that are disected by river drainage valleys of the Withlacoochee and Hillsborough Rivers.

To produce the three-category image of wetlands, pine flatwoods, and uplands, as shown in Figure 9, the subcategories are merged in the computer and imaged in the three colors; blue denoting wetlands, green denoting pine flatwoods, and red denoting uplands. Black, in the nine and the three-category image, represents uncategorized land cover.

The categories and corresponding colors used in the three category imagery follow:

WETLANDS

BLUE. Composite of water, fresh water marshes, bayheads, cypress heads, mixed marshes, and other wetland categories. Mostly wet.

PINK FLATWOODS

GREEN. Composite of natural to managed rangeland, improved pasture, and reforested areas. Mostly wet to poorly drained.

UPLANDS

RED. Composite of sandhills, citrus groves, extractive earth, and other areas of residential, disturbed, or bare earth. Mostly well drained.

UNCATEGORIZED

BLACK. This category includes all targets that do not exceed the probability thresholds established by the investigator.

Because of the edge effect in the photographic processing of the composites of separates of black and white negatives assigned to represent the computer-generated pine flatlands and uplands categories, a yellow bloom was developed. The yellow bloom border actually shows where approximately

equal portions of pine flatwoods and uplands should occur. This edge effect also causes a light blue bloom where pine flatwood and wetland categories are mixed. The light blue areas are mainly gradational downslope from pine flatwood areas to wetlands and are, consequently, wetter and more subject to frequent flooding than the green color-coded pine flatwood category.

The three-category image demonstrates the poorly-drained basin characteristics of the Green Swamp. A basin of wetland and pine flatwood categories; color-coded blue and green, respectively; are bordered mainly by well-drained uplands, coded red. Consequently, the Green Swamp is a large, broad, and relatively flat swamp, composed mainly of wet to poorly-drained wetlands to the north and poorly-drained to moderately-drained pine flatwoods to the south.

CONCLUSION

Because the Green Swamp basin is predominantly wetlands and pine flatwoods and since these categories are wet to poorly-drained, planners and developers will encounter periodic flooding and drainage problems in the central portion of the Green Swamp. Development for optimum drainage is somewhat limited to the upland categories around the borders of the Green Swamp which occur as sandhills and ridges, with intermittent sinkhole lakes, and swampy areas.

Skylab S-192 data provide a useful tool for synoptic appraisal of land-cover types and environmental analysis that could provide developers and planners with an overview of development problems that they may encounter in large and complex areas such as the Green Swamp.

Primarily because of the addition of bands at longer wavelengths, the S-192 data appear to be more useful for delineating categories in the Green Swamp than LANDSAT-1 data.

Those Skylab S-192 bands that are most useful for delineating land-water cover categories in the Green Swamp area are as follows: Band 11 most significant, Band 8 second-most significant, and Bands 7 and 13 are third-most and similar.

Because of the additional spectral resolution available in the S-192 data, it is possible to categorize complex areas, such as the Green Swamp, with great accuracy, provided the investigator has the adequate ground truth needed to establish the many subcategories and to merge them into logical composites.

RECOMMENDATIONS

Categorization accuracy tables and imagery should be generated from noise-filtered S-192 data using the training areas defined by this study. Comparisons should then be made with the non-filtered data to establish the value of noise filtering.

To have transfer value, the techniques and knowledge developed by this investigation should be applied to other areas of the world where Skylab S-192 data are available. There should be included in this selection of additional test sites another wetlands area, an arid environment site, and possibly a glacial site.

The spatial resolution of the S-192 data should be investigated further to establish needs [illegible] wetlands categorization and mapping.

Those bands that contribute most significantly to categorizing land-cover types in the Green Swamp test site should be selectively used to determine the value of selecting fewer bands for automatic processing. This should be particularly important to guiding the selection of bands for future space instruments.

The geometric quality of the categorized imagery should be further evaluated. One procedure for accomplishing this would be to generate categorized map overlays (Ref 7) and to compare the overlay data to base maps and aerial photographs.

REFERENCES

Specific References

1. Space photograph instrumental in ending suit over crucial Florida water recharge resource; National Aeronautics and Space Administration news release (KSC-90-74).

2. R. W. Pride, F. W. Meyer, and R. N. Cherry; 1966; Hydrology of Green Swamp Area in Central Florida; Florida Geological Survey, R.I. No. 42.

3. J. R. Anderson; Land-Use Clr ssification Schemes; Photogrammetric Engineering, Vol XXXVII, No. 4, April 1971, pg 379.

4. R. H. Dye; Multivariate Categorical Analysis; Bendix Special Report, BSR 4149, 3 June 1974.

5. R. H. Dye, D. S. Hanson, and C. L. Crawford; Signature Data Processing Study; Bendix Report, BSR 2949, NAS 9-9848, August 1970.

6. J. Anderson, E. Hardy, and J. Roach; A Land-Use Classification System for Use with Remote Sensor Data; Geological Survey Circular 671, Washington, 1972.

7. R. H. Rogers and L. E. Reed; Automated Land-Use Mapping from Spacecraft Data; Proceedings National ASP Meeting, St. Louis, Mo., March 1974.

General References

8. Final Report and Recommendations for the Proposed Green Swamp Area of Critical State Concern, Lake and Polk Counties, Florida; Division of State Planning Bureau of Land Planning, 16-74, June 1974.

9. R. W. Pride, F. W. Meyer, and R. N. Cherry; 1971; Interim Report on the Hydrologic Features of the Green Swamp Area of Central Florida; Florida Geological Survey I.C. No. 26.

Table I

SKYLAB S-192 AND LANDSAT-1 MSS BANDS

S-192		LANDSAT-1	
Band No.	Band (Microns)	Band No.	Band (Microns)
1	0.41 - 0.46		
2	0.46 - 0.51		
3	0.52 - 0.56		
4	0.56 - 0.61	4	0.5 - 0.6
5	0.62 - 0.67	5	0.6 - 0.7
6	0.68 - 0.76	6	0.7 - 0.8
7	0.78 - 0.88		
8	0.98 - 1.08	7	0.8 - 1.1
9	1.09 - 1.19		
10	1.20 - 1.30		
11	1.55 - 1.75		
12	2.10 - 2.35		
13	10.2 - 12.5		

Table II

CATEGORIZATION ACCURACY TABLE USED TO EVALUATE SELECTION OF TRAINING AREA

Category	Subcategory	Category Number								
		1	2	3	4	5	6	7	8	9
Wetlands	1. Cypress	86	0	1.3	0	4.5	0	0.6	7.6	0
	2. Water	0	100	0	0	0	0	0	0	0
	3. Fresh Water Marsh	0	0	100	0	0	0	0	0	0
	4. Bayhead	0	0	0	99	0	0	1	0	0
	5. Mixed Wetlands	11.5	0	0	0	88.5	0	0	0	0
Pine Flatwoods	6. Improved Pasture	0	0	0	0	0	98	2	0	0
	7. Mixed Palmetto	0	0	0	0	0	0	94	6	0
	8. Pine	0	0	0	0	0	0	0	100	0
Uplands	9. Citrus	0	0	0	0	0	0	0	0	100

Table III

AUTOMATIC TABULATION OF CATEGORY AREAS

Major Category	Subcategory	Percent of Total Area	Square Kilometers	Acres
Wetlands	Cypress Heads	16.36	1,318.6	325,852
	Water	3.83	308.9	76,327
	Fresh Water Marsh	4.43	356.8	88,167
	Bayheads	2.06	165.8	40,977
	Mixed Wetlands	3.08	248.1	61,306
	Wetlands Summary	29.76	2,398.2	592,629
Pine Flat-woods	Improved Pasture	5.08	408.7	100,984
	Mixed Palmetto	22.64	1,824.6	450,894
	Pine	5.17	416.6	102,958
	Flatwoods Summary	32.89	2,649.9	654,836
Uplands	Citrus	26.79	2,158.9	533,486
Uncategorized		10.56	850.7	210,222
Total		100.00	8,057.7	1,991,173

Note: One S-192 pixel = 1.676 acres.

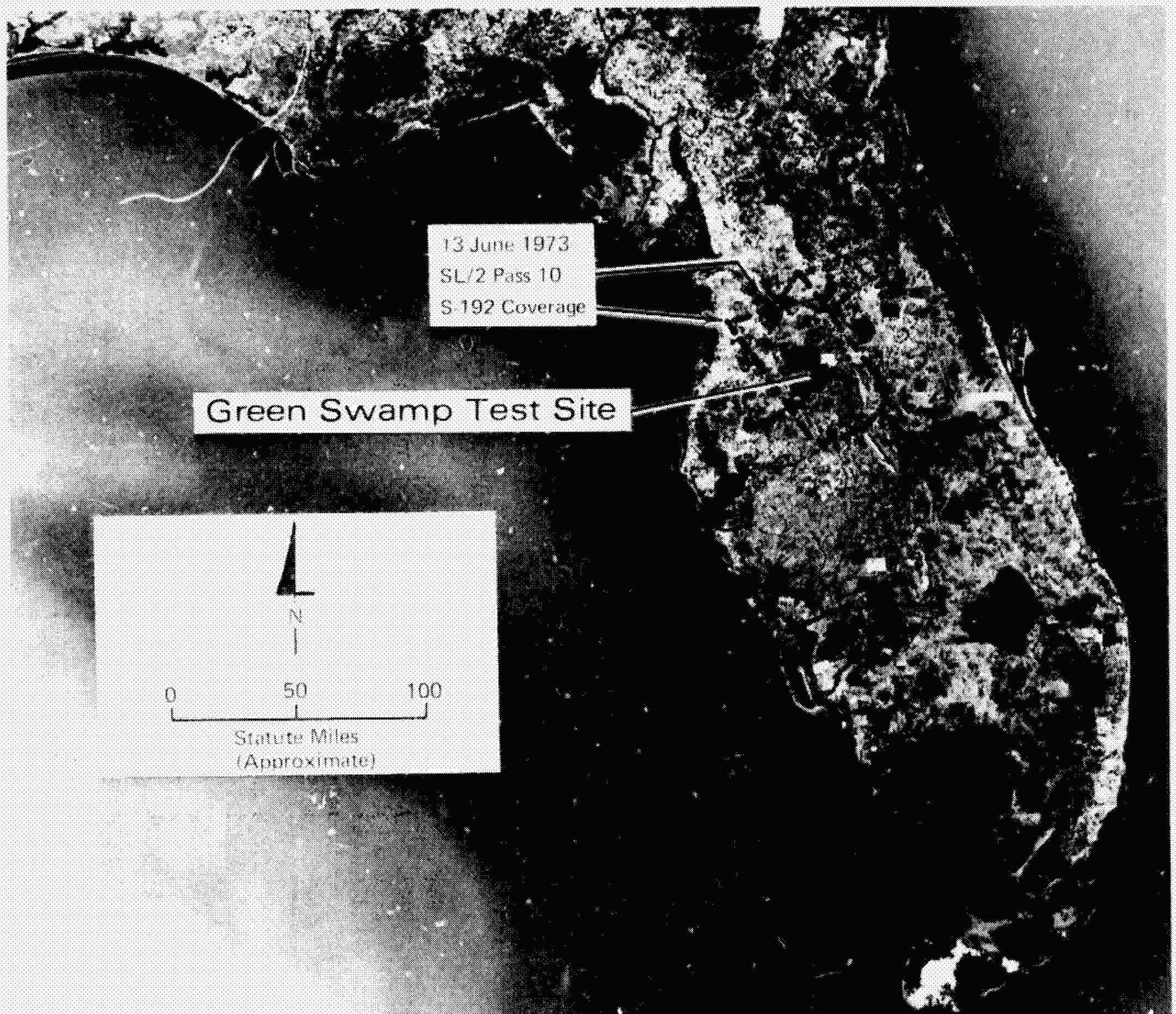


Figure 1 Location of the Green Swamp Test Site, Florida

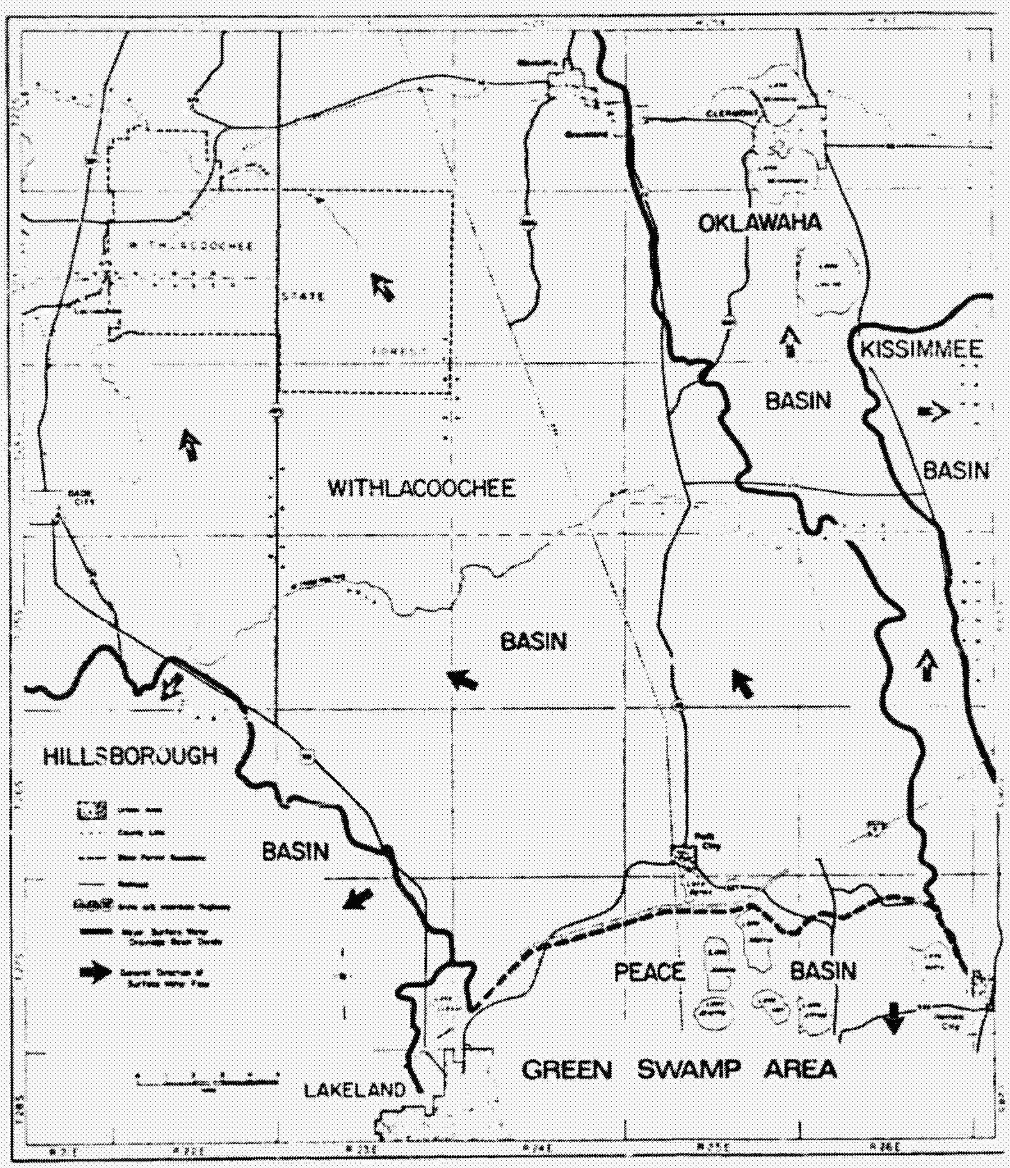


Figure 2 Green Swamp Test Site, Showing Major Surface Water Drainage Basins and General Direction of Surface Water Flow

Figure 3 Machine processing of Skylab EREP S-192 data

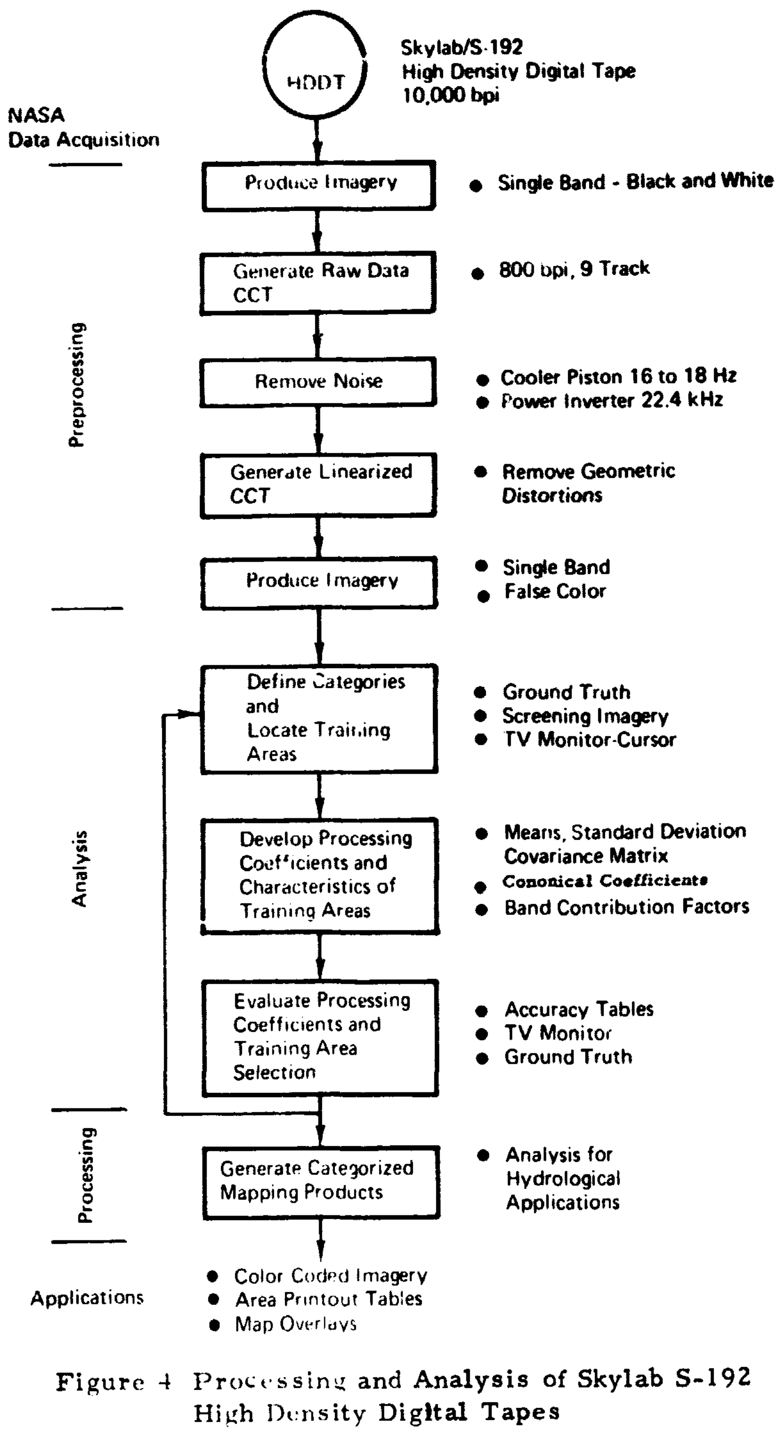


Figure 4 Processing and Analysis of Skylab S-192 High Density Digital Tapes

SKYLAB S192 IMAGERY OF THE FLORIDA GREEN SWAMP

SL/2 T-6 PASS 10, JUNE 13, 1973

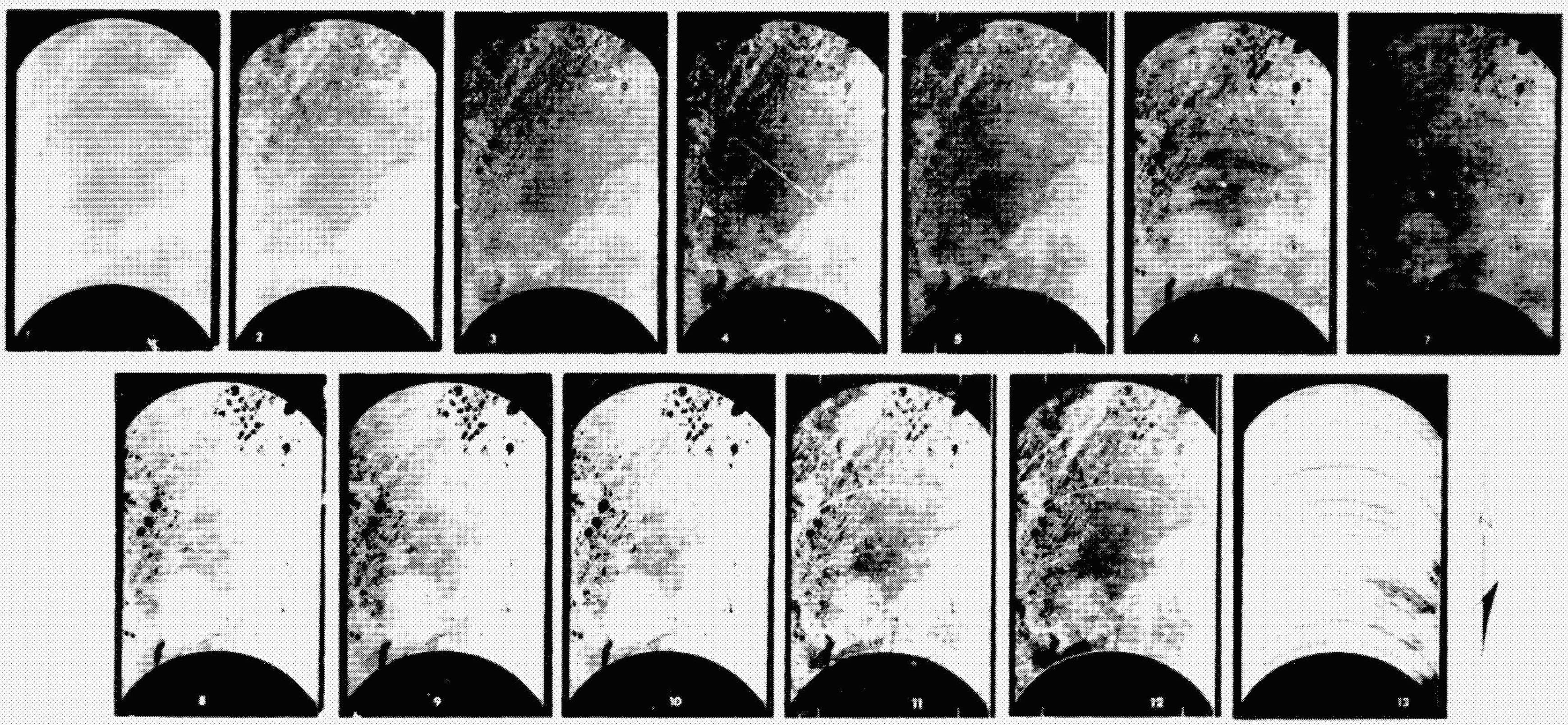


Figure 5 Skylab S-192 Imagery of the Florida Green Swamp;
SL/2 T-6 Pass 10, 13 June 1973

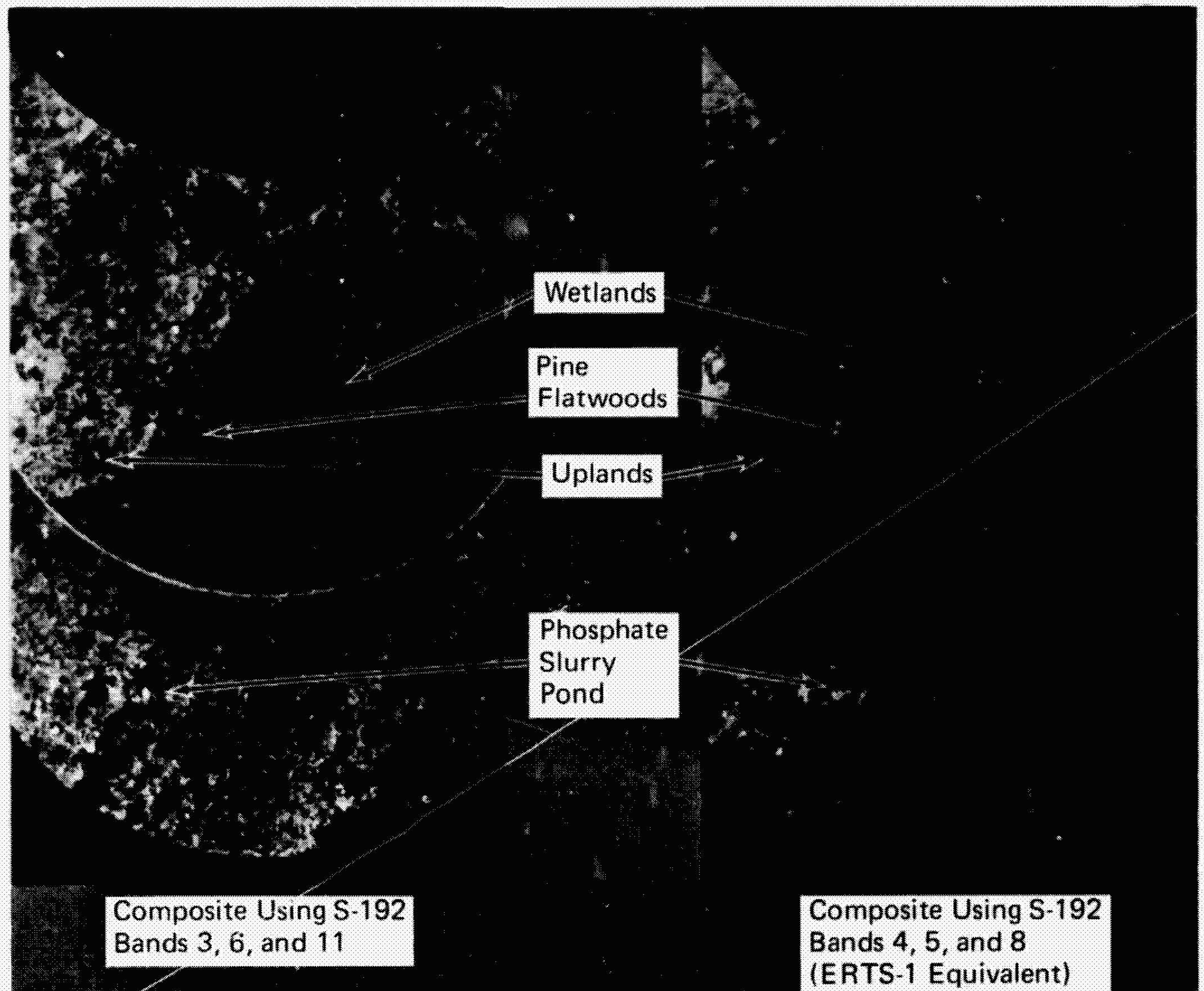


Figure 6 Color Composite Images of Skylab SL/2, S-192 Bands
Showing Advantages of Using Spectral Combinations
Differing from LANDSAT-1 Bands

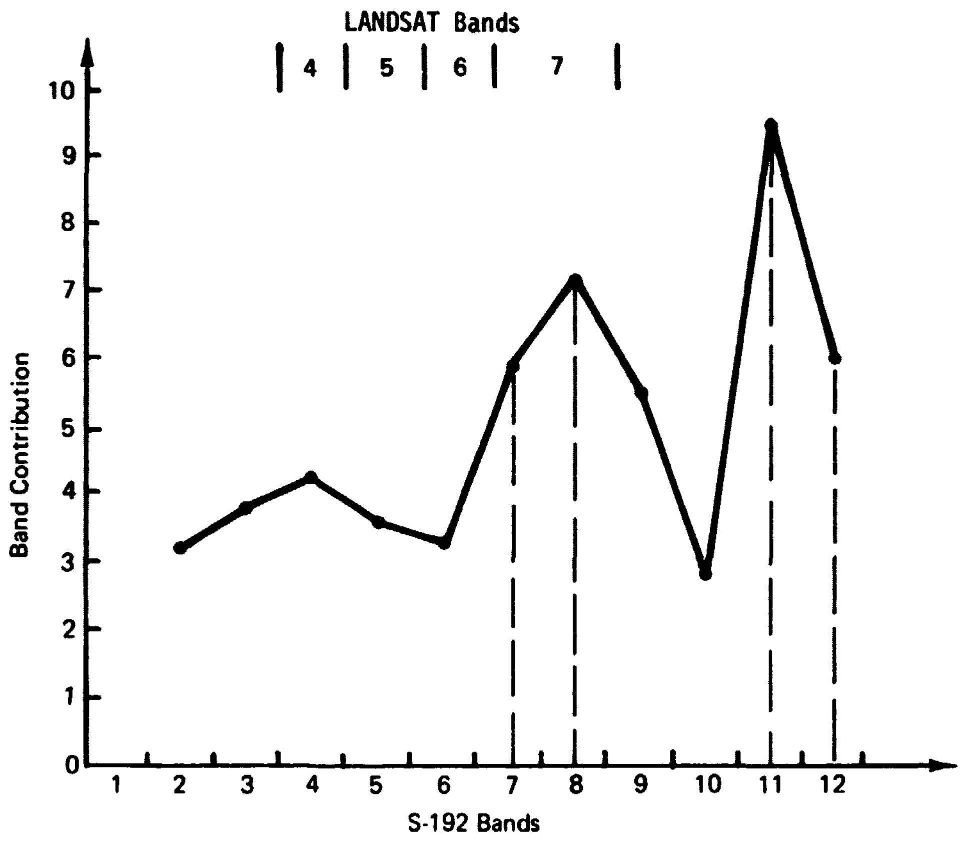


Figure 7 Relative Band Contribution of Skylab S-192 Bands for Automatic Categorization of Land-Water Cover Types of the Green Swamp, Florida

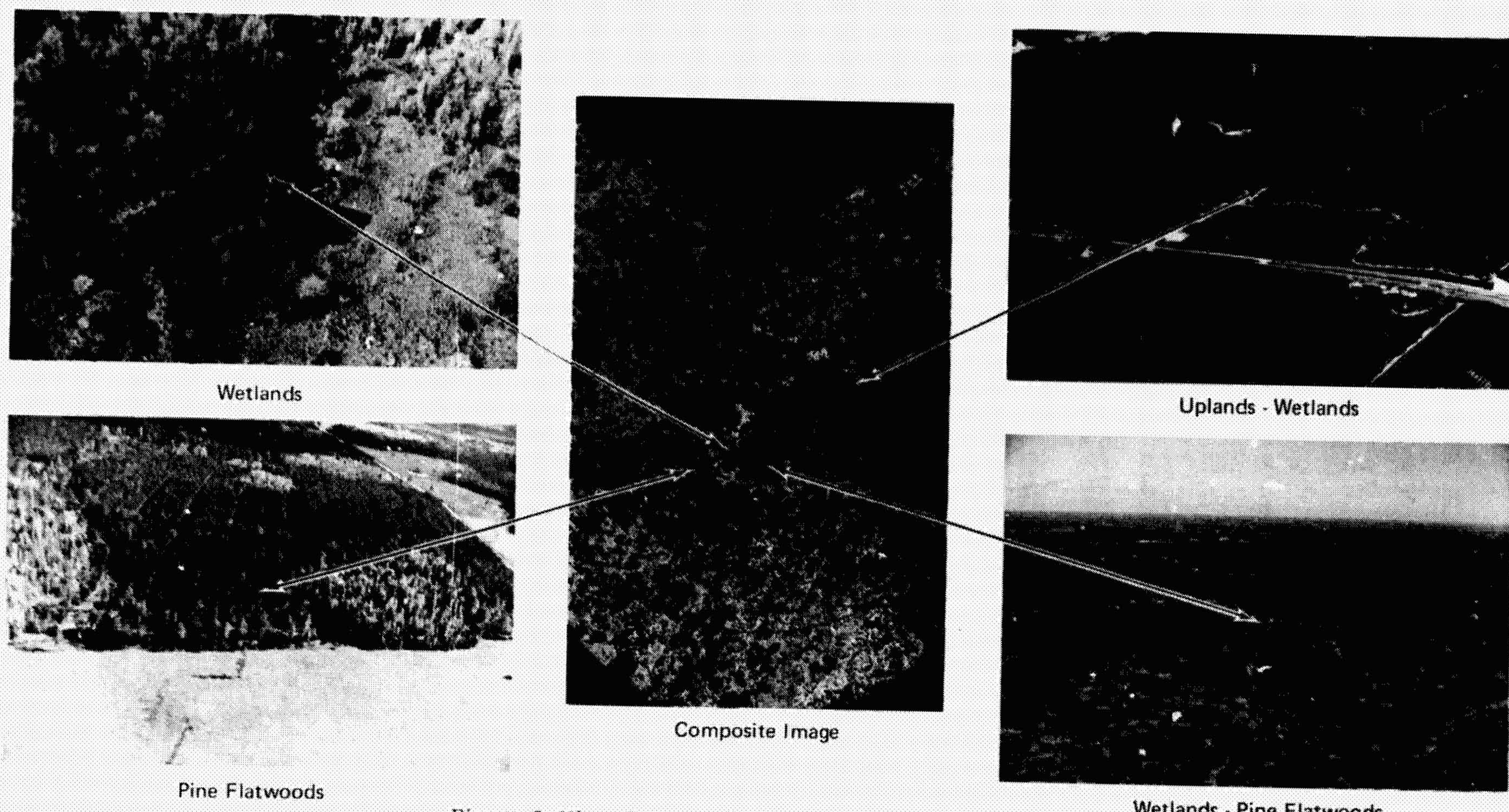


Figure 8 Nine-Category Image from Skylab S-192 Data and Examples of Ground Truth Areas

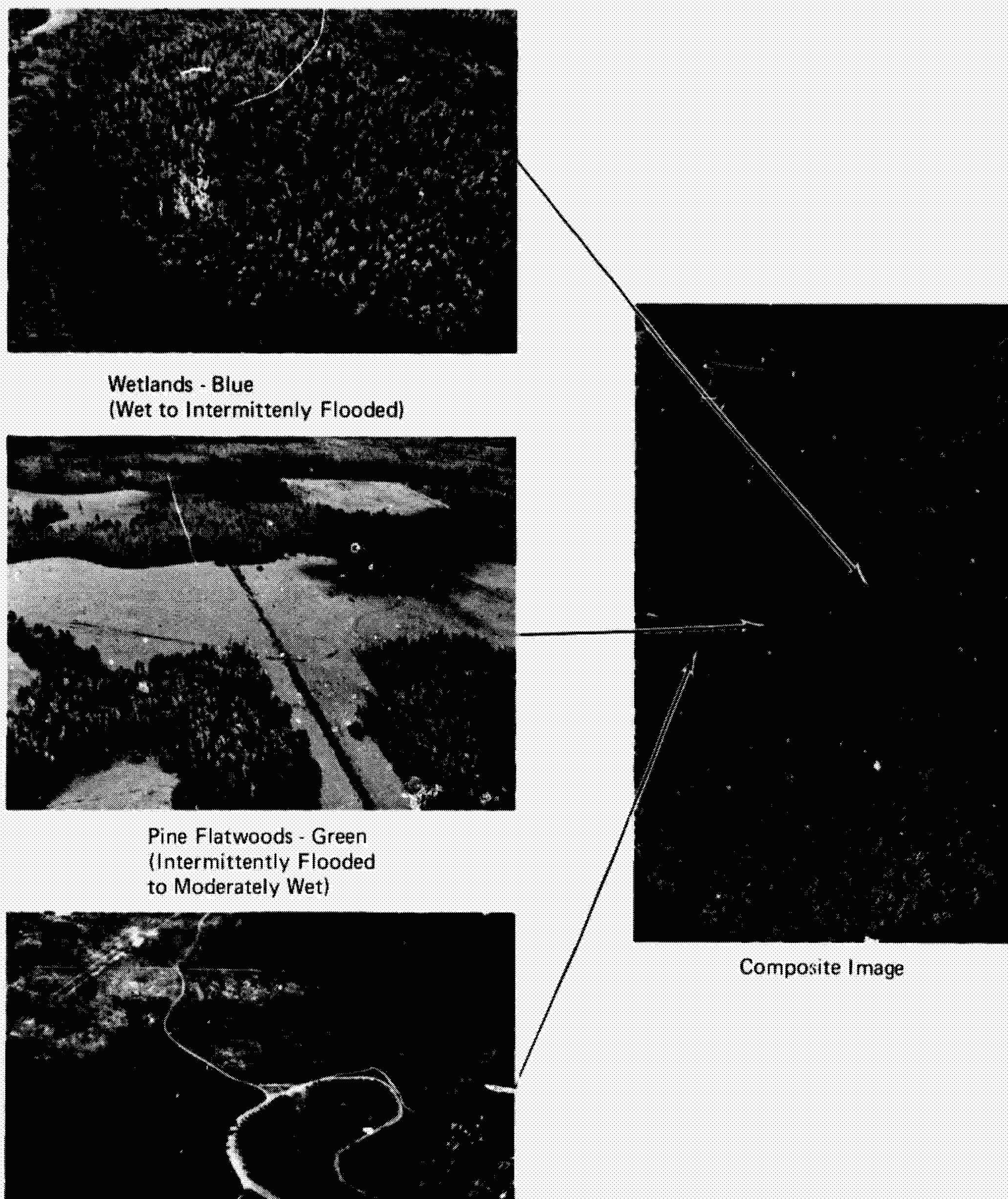


Figure 9 Three-Category image from Skylab S-192 data showing wetlands, pine flatwoods and uplands.

A COMPARATIVE INTERREGIONAL ANALYSIS OF SELECTED DATA FROM LANDSAT-1 AND EREP FOR THE INVENTORY AND MONITORING OF NATURAL ECOSYSTEMS

E-16

By Charles E. Poulton, Earth Satellite Corporation,
Berkeley, California

N76-17500

ABSTRACT

The paper presents comparative statistics on the capability of LANDSAT-1 and three of the Skylab remote sensing systems (S-190A, S-190B, and S-192) for the recognition and inventory of analogous natural vegetations and landscape features that are important in resource allocation and management. Investigations were conducted in two analogous regions presenting vegetational zonation from salt desert to alpine conditions above timberline. The visual interpretation mode was emphasized in the investigation. An hierarchical legend system was used as the basic classification of all land surface features. Given adequate ground truth and a knowledge of what to expect ecologically within each region, it was possible to map and identify many features to the fourth hierarchical (first floristic) level in the classification system. Fourth level decisions were, however, strongly based on recognizing associated features and convergence of evidence. Identifications at second and third levels (physiognomic and structural criteria) were generally photo identifiable by knowledgeable interpreters. Comparative tests were run on image identifiability with the different sensor systems, and mapping and interpretation tests were made both in monocular and stereo interpretation with all systems except the S-192. Significant advantage was found in the use of stereo from space when image analysis is by visual or visual-machine-aided interactive systems. Some cost factors in mapping from space are identified. The various image types are compared and an operational system is postulated.

INTRODUCTION

The project we are reporting today had its origin with investigations which the author and his associates conducted starting with Gemini IV and Apollo VI and IX experimental earth resources photography. During these investigations work was begun on a uniform system for the inventory and monitoring of vegetational resources and natural environmental complexes by appropriate combinations of space, aircraft imagery, and ground work. The research was continued through the LANDSAT-1 experiment and into Skylab for the purpose of further development and refinement of the uniform system for interregional application and to make comparative tests of three of the sensor systems aboard Skylab.

Our working hypothesis has been that analogous vegetations and environmental complexes should have sufficiently analogous remote sensing signatures (at some appropriate level of classification) that they could be recognized widely throughout a region and, hopefully, in each of many regions from subject-image relationships worked out at a few representative locations. Given appropriate image quality control or radiometric fidelity, we have been able to accept this hypothesis as operationally feasible at various specified levels of classification in the hierarchical legend system we have been using to characterize the vegetation-landform systems that comprise the ecosystem units of the earth's land mass. Other work by Earth Satellite Corporation outside this project has also provided the opportunity successfully to apply the concepts on a global basis--on four continents.

Space technology now permits us to acquire both operationally useable photography and multispectral scanner data from space--the former with very good spatial resolution and

the latter with very good radiometric fidelity. Such imagery is appropriate to a broad spectrum of natural resources applications. It has given us the particular capability:

1. To image and analyze vast areas of the globe in a very short period of time,

2. To obtain very broad synoptic coverage and thus to transcend boundaries of agency and ownership responsibility and even of political jurisdiction,

3. To view both multidate and multispectral scenes simultaneously in reaching interpretive decisions about earth resources, and

4. To put earth resources and their use in a vivid, pictorial perspective provided that regional, national, or global systems of identification and annotation are developed and used.

Historically man has evaluated and planned the development, use, and management of earth resources; first from the highly restrictive view provided by ground observation, then from the substantially improved perspective of conventional aerial photography, and most recently from the still broader perspective obtainable from an earth-orbiting spacecraft. Also, historically speaking, the earth resources themselves have been managed quite restrictively by a multiplicity of government and private interests and, particularly, in the United States with each having its own local or restricted regional point of view. Consideration of resource problems in the context of small-to-major watersheds is about as close as we have traditionally come to development of a broad synoptic view of problems and their interrelationships. In this context, it has neither been necessary to develop a unified procedure for the identification of earth resource features across broader regions, nor a truly national or global legend for their identification and annotation. Each agency, landowner, or river basin commission could achieve its stated objectives by developing its own techniques and legends, largely independent of the views and need for coordination with others. After all, the project boundary seemingly was the true limit of concern.

When, on the other hand, we consider the ever-increasing dependence of one region or nation on another for food, fodder, fiber, and minerals and also for environmental protection, this limit of concern broadens commensurately. It is in this context that remote sensing from an earth-orbiting spacecraft assumes its greatest potential significance. The synoptic view offered from such a platform makes it possible for a single unified legend system and identification method to be applied across all ownerships throughout a vast area and then to draw together what each responsible agency knows into a common, integrated data base--much of which can be pictorially portrayed on a space-derived image or mosaic. It becomes even more appropriate in this setting to take an ecological approach to resource inventory and environmental monitoring when relating each kind of resource area to its land use potential and management requirements. It has been my purpose through these almost 9 years of applications research to contribute to these kinds of goals and capabilities.

The specific objectives of the investigation now being reported are:

a. Further test and refine a uniform, hierarchical classification and legend system for the identification of natural vegetation and land surface characteristics from space and aircraft imagery,

b. Specify potentialities and limitations of the uniform legend concept for multistage, interregional, and potential global application and define the kinds of analogs that can and cannot be interpreted from the various types of space imagery,

c. Evaluate the contribution of stereo interpretation of space imagery to the accuracy of delineation and identification and for increasing the specificity of interpretable analogs,

d. Evaluate the effect of spatial resolution on interpretability, and

e. From comparative studies of stacked data over the same test sites, postulate an efficient multistage system for inventory and monitoring of natural ecosystems and man's impact upon them.

TEST REGIONS

To investigate problems implied by these objectives, we selected two widely separated test regions in the two major mountain chains of western North America (Figure 1)--the Colorado Plateau of southwestern Colorado and adjacent states and the Sierra-Lahontan of California and adjoining Nevada in the vicinity of Eastgate to Reno, Nevada and Lake Tahoe. The approximate local extent and shape of each test region is shown in Figure 2. Each of these test regions presents an analogous sequence of vegetational types from the salt desert to rocklands above timberline.

The Colorado Plateau Test Region

This test region includes vegetation zonation patterns highly similar to the Sierra-Lahontan with many vegetation analogs as well as a few vegetation types unique to its surrounding area (Figure 2). The zonation pattern within the Colorado Plateau Test Region is from the salt desert (Atriplex dominant) zone, through the sagebrush* or shrub steppe, pinyon-juniper, oakbrush, ponderosa pine, to aspen and spruce-fir, with some essentially alpine vegetation associated with the high mountain rocklands above timberline. A mixed coniferous type (Douglas fir, true fir, and ponderosa pine) occurs in the area, but it is generally restricted to northerly aspects in the intermediate and upper elevations of the ponderosa pine zone. The spruce-fir zone is well-defined immediately below timberline. The two regions are contrasted particularly in the high preponderance of the deciduous Gambel oakbrush type of the Colorado Plateau with very limited distribution of sclerophyllous shrub types, such as manzanita.

The area has important geologic and mineral significance but in these respects is strongly contrasted to the Sierra-Lahontan. There are rather extensive areas of irrigated agriculture heavily oriented to livestock ranching. Forestry, mining, recreation, and wildlife are important in the region. This test area includes parts of two Indian reservations and large amounts of Bureau of Land Management and federal Forest Service land.

The Sierra-Lahontan Test Region

Direct analogs with the Colorado Plateau Test Region occur here. They are found in the salt desert zone, the sagebrush or shrub zone, the pinyon-juniper zone, and also in the Jeffrey pine zone, which is analogous with the ponderosa pine zone of the Colorado Plateau. In the Sierra-Lahontan Test Region, the spruce-fir zone is not distinctive as in southwestern Colorado. The spruce-fir of the latter test area is ecologically but not floristically analogous to the mountain hemlock types below timberline in the

*For scientific names of important species see the Table of Analogs, Appendix A.

Sierra-Lahontan Test Region. One might expect the signatures of these two types, however, to be similar. In the latter area, the sclerophyllous shrub type predominates in most of the forest openings, and Gambel oakbrush is entirely absent. Deciduous oak trees are, however, present in the Jeffrey pine zone. This is in floristic contrast with the common occurrence of Gambel oak in the understory of ponderosa pine forests in the Colorado Plateau Test Region. In spite of the floristic contrast, these two types are ecologically analogous and one might expect their signatures to be similar in the two regions. The mixed conifer type (more extensive in this region) is essentially analogous with the north-aspect, mixed conifer types of the Colorado Plateau. An idealized picture of the vegetational zonation pattern in the two regions is shown in Figure 3.

There is an Indian reservation in the Sierra-Lahontan Test Region with similar preponderance of other federal land. The patterns of agriculture and crop types are highly similar with livestock production being a significant part of the local economy. Wildlife and recreation are also very important in this region. Aspen types occur but are much more restricted than in Colorado. The two regions are strongly contrasting geologically but, in spite of this, good vegetational analogs do occur.

IMAGE AVAILABILITY

For the quantitative work under this project we settled on relatively small areas near Cortez, Colorado and Pyramid Lake, Nevada, where, in spite of the interminable problems of clouds, mission scheduling, and performance, and high-flight support acquisition we did in fact have useable examples of all image types available superimposed over an identical area in each region. The available imagery that we were able to use in the experiments (exclusive of the high-flight that was used primarily for ground truth confirmation on identifications and experimental mapping) is summarized in Table I. The only serious problem arose when choices were made in favor of the all-important data superimposition (stacking) requirement. Interregional variation in photographic quality for the S-190A and S-190B systems as well as the high-flight photography made direct experimental testing of interregional interpretability with the photographic data impossible. In addition, a large part of the Sierra-Lahontan imagery lay outside our area of maximum ground truth although it had been covered by over-flight aircraft observations in some detail and by two limited ground truth missions. Considering this problem, all of our experimental mapping was limited to the Colorado Plateau Test Region, where the data stack also covered an area of high ground truth density. Formal photo interpretation tests were possible in both regions as individual experiments.

A PRACTICAL SETTING FOR EVALUATION

As we approach the question of the extent to which and how remote sensing imagery from space can be incorporated into the practical solution of natural ecosystem problems, it is important to recall to mind the relationships between scale and resolution in the resource use and management decision process. Each problem and level of administrative-management has its own general scale requirements for decision making. When we say resolution in this case, we mean both spatial and spectral, because there is a strong trade-off between the two which usually, in the practical context, has to be compromised. We can rarely have the best of both worlds, since for some solutions spatial resolution holds the key while in other cases spectral resolution makes the greater contribution. The question can be disposed of by saying that it would be the grossest error to place emphasis only on one or the other.

What one can derive from remotely sensed data is strongly and directly dependent upon the practical problem to be solved. There are levels of problems just as there are levels of scale and refinements in resolution. These interrelationships are recalled to mind by Figure 4. In the complete management context, scales of 1:250,000 and smaller are

superior for many problems in policy and broad planning. On the other extreme in practical resource management, especially in rangeland resources and forestry, sample point imagery at scales as large as 1:1,000 to 1:600, are often required if the contribution of remote sensing to efficient management is to be maximized.

Thus, we are addressing the question, "What is the role of space and high-flight imagery in this total process?" We are not at all concerned with the question, "Can or will space and high-flight imagery from presently available systems replace conventional aerial photography?" The most effective operational system is a combined one. For specific problems it may or may not require a space component.

METHODS

Ground Truth Activities

Ground truth consisted of:

a. Vegetational and soil resource maps provided by cooperating federal agencies in the respective regions.

b. Ground observations made by EarthSat scientists at or near the time of overpass.

c. Supplemental notes and observations, particularly on vegetation phenology (seasonal development), by agency cooperators.

d. Low level aerial photography, vertical and oblique, flown by EarthSat staff at or near the time of key seasonal overpasses by Skylab.

e. High-flight photography provided by NASA.

The legend categories to fourth and fifth level were used directly for field and air-check documentation. All of our ground truth data were plotted on 1:250,000 topographic sheets by numbered keys to facilitate relating them to each of the space imagery (Figure 5). Each of these locations was then transferred to a LANDSAT-1 1:250,000 enlargement with each datum point identified by legend symbol. Most of our critical mapping and interpretation experiments were done on 1:250,000 enlargements of the space image although some work was done on the duplicate 9x9 transparencies provided by NASA.

Image Interpretation Testing

Three separate interpretation tests were run using students from the remote sensing classes at the University of California, Berkeley. Groups of interpreters were selected on the basis of performance in the first-year course. None had had significant prior experience in photo interpretation. For each of the tests, ten students were assigned to two major groups consisting of five interpreters each. In the first test these groups evaluated the imagery by making a total set of 2400 decisions on each of eight image types. The image types evaluated were from the Colorado Plateau only and consisted of the eight types shown in Table II. In the first test imagery at the appropriate scale of 1:110,000 was used. In the second test, similarly constituted but different groups of interpreters evaluated imagery from both regions with all images enlarged to the common scale of 1:250,000. In this test five examples of each tester analog were evaluated for each image type (Table II) to give a total of 250 decisions per image type in the two regions combined.

In both of these tests, training examples of each tester analog were identified on the imagery. Remaining examples were located and randomly numbered. The interpreters were given five minutes to study the training sets on each image type and 30 seconds each to identify each member of the numbered test set. These data were analyzed by Tukey's method of pairwise comparison and by the conventional commission-omission error analysis. In a third image interpretability experiment with the first of the above interpreters, ten individuals repeated the test by the interpretation of LANDSAT-1 in side-lap stereo. Subjective evaluations of interpretability were also made by highly experienced interpreters.

Mapping Experiments

All mapping experiments were performed on 1:250,000 enlargements of the color imagery. In addition, the full 13 seconds of S-192 color composited data were mapped at the scale of the imagery as provided by NASA in five-inch film format (approximately 1:737,000).

A set of mapping criteria and guidelines were prepared and all imagery types were mapped according to these guidelines by a single interpreter to avoid variation in method since the primary purpose was to evaluate the various types of imagery. After doing the mapping in monocular examination, each area was additionally evaluated in stereo and notes were taken on the amount of line changes and number of identifications corrected as a result of the better perception of elevational and land-form relationships.

As the mapping was done, the interpreter assigned each boundary delineation a "certainty of delineation" and an "identifiability" rating according to the criteria in Tables III and IV, respectively. These data were then summarized by image type and evaluated for indications of the superiority of image type.

These results were compared among image types as an assessment of possible benefits from the use of stereo from space and also to determine if there were differences among image types with and without the stereo contribution to the interpretation process.

The same test area was mapped and each analog identified from RC-8, color infrared high-flight photography. On this the legend units were positively identifiable and except for the problem of generalizing the mapping to somewhat correspond to the intensity used on the space imagery, type delineation was very accurate. These maps were then compared as regards the kinds and nature of analogous features within each mapping unit on the five kinds of space imagery evaluated in the second test (Table II). As an additional check for the southern part of the test area, mapping was compared with vegetation and soils maps prepared by the Bureau of Indian Affairs and some Forest Service type maps provided spot checks in other areas.

In addition, 16 relief conditions were identified and measured from 1:250,000 topographic sheets. These points were located on each image type and evaluated as to the clarity with which they could be perceived in stereo examination. These results were summarized to compare image types and to establish the relief thresholds discernible with each type of imagery. The stereoscopic comparison was made at both the 1:250,000 scale and the 9x9-inch NASA product duplicate scale of approximately 1:737,000. In all cases transparency materials were used--for interpretation testing and mapping experiments.

Finally, based on our accumulated experience, the above evaluations, and the operational use of space imagery in the EarthSat applications program, a flow diagram was developed for a suggested operational system to analyze landscapes by appropriate combinations or alternatives of space imagery and aircraft photography.

Classification and Legend System

Since the first involvement of the author with space imagery in 1966, he and his associates have been evolving an hierarchical legend system under a consistent set of discriminative criteria. The system is especially suited to multistage remote sensing application and is decimal numerical for computer compatibility.[1] This effort has stabilized into a format and set of classification categories that is published elsewhere and has enjoyed widespread practical application in comprehensive ecological analysis of earth resources and land use studies.[2,3]

From the standpoint of plant ecology, vegetation and soil resource management, a classification and characterization of the form of the land surface is extremely important to both the student of landscapes and resource ecology and to the resource manager. For many years in the author's research at Oregon State University and in projects involving his graduate students, they have used a three-component system for landscape characterization. The components are: macrorelief, landform, and microrelief.

Macrorelief refers to the largest categories of classification of major relief change within the landscape system being described. Landform refers to the specific form of the landscape as a secondary level characterization. The classes we have devised to this date are consistent with and accommodate the major landform features recognized by geomorphologists within the two broad categories of fluvial and desert erosional characteristics or provinces. They also accommodate equally well the concept of features of negative and positive relief, i.e., high features and depressional features.

After trying repeatedly to use the technical landform classifications of the geomorphologists, we have gone back to a set of classes, with some modification and improvement, similar to the ones the author started to use in the early 1950s while conducting vegetation-soil relationships studies in forested and rangeland environments. While these classes may cause the professional geomorphologist some pain, they do have the distinct advantage of being especially relevant to and capable of depicting the kinds of landform features that are most relevant to plant ecology and soil development and to the practical use, development, and management of earth resources.

The microrelief classes define the contour of local landscapes, features of very low relief. For example, they express the micro-contour of a single mountain slope, small undissected mesa, or valley bottom.

Most of the classes or categories have been previously described and illustrated in various of NASA reports and other publications where they do not make use of common terms described in the geomorphological literature. Thus in the interest of time and space, descriptions of the classes are not included herewith. It is sufficient for the purposes of this paper to merely indicate the format of the system (Figure 6). The legend for all analogs evaluated in this project and for the characterization of the land surface is presented in Appendix A. The one new development that came out of this project was an improvement and refinement in the macrorelief and landform classes over that presented in 1972 (2). The major change involved bringing all classes under the same decimal numeric system and revising the landform classes to more logically accommodate the land surface features that are ecologically significant in vegetation and soil development and in land use and resource management decisions (Figure 7).

RESULTS AND DISCUSSION

Quantitative Comparison of Image Types for Interpretability

The purpose of these quantitative tests was to determine which of five image types were superior for ocular identification of natural vegetation analogs in the two test regions. The analogs used in the test are shown in Table V. An "Other Vegetation Types" class was included so that a variety of unknown image types could be interjected into the testing to create possible confusion with the subject analogs and thus provide a better assessment of true interpretability.

In conducting the test, the students were given a brief discussion of the common vegetational zonation patterns in the two regions and the various analog types were described so they would have some feeling of familiarity with the subject areas. In the familiarization discussion, no mention was made of image characteristics associated with the vegetation analogs.

The image set for the Colorado Plateau test region represented green season phenological development in the lower and middle altitudes, and pre-emergence dormant season at the very highest altitudes. The full-development, green condition prevailed generally below 9,000 feet elevation and pre-emergence dormant season essentially above 9,000 feet, except for evergreen species. The Sierra-Lahontan test area represented the dormant season condition below approximately 6,000 to 7,000 feet, and green mature vegetation conditions above approximately 7,000 feet. These particular dates in each of the two regions were selected because they were the only dates on which we accumulated useable, essentially cloud-free imagery for all image types over the same area. A much more desirable test would have been achieved had it been possible to use both green and dry season imagery for both of the analogous regions.

<u>Interpretation Test One</u>.-

Statistical Analysis: On the basis of Tukey's method of pairwise comparison, the image types compared in Test One can be ranked in order as shown in Table VI. From this table it is seen that the two best image types are S-190A color infrared and LANDSAT-1 color composite. S-190B color ranks third, thus its higher resolution on color film did not compensate for the color infrared spectral qualities. It is interesting also that black-and-white infrared imagery ranked close alongside S-190B color in this test with the suggestion that both black-and-white types (LANDSAT-1 and S-190A) may be more accurately interpretable for the point identification of vegetation analogs than S-190A color. The red band imagery was poorest of all.

It is informative to consider the image types that resulted in the fewest commission errors for each vegetation analog in this more comprehensive single-region test. These results are presented in Table VII.

The importance of high resolution in the S-190B color is evident in its superiority for identification of the sedge meadow analog. Sedge meadows are narrow stringer types in this region. They rarely occur except in narrow valley bottoms and around the edge of small lakes. Such features can only be seen and correctly interpreted on S-190B.

With the general inferiority of black-and-white broad band imagery for visual interpretation one might wonder why S-190A black-and-white infrared was among the best image types for aspen, spruce-fir, and the "other natural vegetation" categories. With the test imagery taken in the summer green season, aspen would be very highly reflective, thus producing unusually light tones in sharp contrast to the spruce-fir which occurs largely in juxtaposition with aspen and would image as a very dark tone on black-and-white infrared. Thus whenever the sharp edge of black on white was observed

on the S-190A black-and-white infrared at high elevations, the logical conclusion would be to identify aspen for the light tones and spruce-fir for the dark tones.

The "other natural vegetation" category was probably interpreted well on S-190B color because we tended to select small contrasting vegetation analogs for the "others" category. It is important also to note that color infrared was superior for five vegetation analogs whereas color was superior only for three analogs. One should recognize, however, that in one instance (S-190B) the opportunity did not exist to compare both color and color infrared from this high resolution system. It is quite likely that the CIR would also have been superior over color film in the S-190B system. In summary, these results indicate the general superiority of color infrared remote sensing products for all natural vegetation interpretations.

Commission-omission error analysis: The results of the more comprehensive Test One are also summarized from a conventional omission-commission error analysis in Table VIII. If one looks first at the percent correct for the eight image types, it is apparent that both LANDSAT-1 color reconstitution and S-190A CIR meet frequently acceptable standards of accuracy, particularly the latter. LANDSAT-1 black-and-white Band 7, S-190A black-and-white infrared, and S-190B color gave essentially the same results; and next to the color infrared renditions, S-190A color and S-190A black-and-white red band were poorest in terms of point identification accuracy.

If one looks at the percent commission error category, comparisons can be made more explicitly (Table IX). This difference matrix shows LANDSAT-1 4, 5, 7 color reconstitution superior to 3 out of 7 other image types. It was better than LANDSAT-1, Band 5, and S-190A color and black-and-white red band. S-190A color infrared was not different but with a non-significant suggestion that it might hold a slight edge over LANDSAT-1 4, 5, 7 reconstitutions. However, this hypothesized advantage would be overridden by the image quality control problems (poor radiometric fidelity) of the S-190A camera system. In our experiment the planned interregional comparisons were impossible because of this problem.

The S-190A color infrared was superior to LANDSAT-1 Band 7 only at a low probability (P=0.90); but it was highly superior to S-190A color. The S-190B color was superior to S-190A color (P=0.95) but also inferior to S-190A color infrared (P=0.90). In all comparisons the black-and-white red or Band 5 was outstandingly poor, with commission errors of 48.7 and 53.5 percent.

<u>Interpretation Test Two</u>.-

Statistical Analysis: Based on experiments performed under this contract in only the Colorado Plateau region during the spring of 1974, we decided that substantially fewer than 2,400 interpretation decisions would provide acceptable results[4]. Both cost factors of employing experimental interpreters and especially the time required to process larger amounts of data, led us to compromise on five interpreters and four tester analogs on the five image types in two regions for these additional comparisons of LANDSAT-1 and Skylab data.

The basic data derived from Test Two are displayed in Table X. These data were first analyzed by a one-way analysis of variance which showed highly significant differences in the Group I Sierra-Lahontan data and significant differences in Group II Sierra-Lahontan data. The accuracy obtainable with the image types in the Colorado Plateau region were not significantly different, although Group II approached significance. Careful study revealed that there was a tendency for variation among interpreters and in image quality to obscure meaningful differences.when all the data were grouped. Using between-region differences in correct identifications with a given image type as an index of regional variation in image quality, or the effect of seasonal difference between regions, the interpretability of LANDSAT-1 data was

different between the two regions at a probability far in excess of 0.99. Similarly, Group II interpreted both S-190A color and S-190B color imagery differently between the two regions at a probability far in excess of 0.99. Only S-190A CIR imagery was interpreted with the same accuracy by both groups in both regions.

The results for Group I and II in the Sierra-Lahontan region and the combined groups for the Colorado Plateau region were then tested for significant differences among all image type comparisons. These data are summarized in matrix Tables XI, XII, and XIII. This analysis shows that, at varying levels of probability (all in excess of P=0.90) the interpretability of LANDSAT-1 data was higher than all other types in the Sierra-Lahontan. Also at varying levels of P=0.90, S-190A color infrared was superior to S-190A color, S-190B color, and S-192, except one instance of a group interaction in the test. Group II gave highly significant superiority to S-190A color infrared over S-190A color, but Group I did not show a difference between these two image types. No other comparisons gave significant results. This suggests that the radiometric qualities of color infrared are more important in contributing to accuracy of interpretation than is the high resolution of the S-190B system. The same can be said with respect to the LANDSAT-1 color infrared rendition, in spite of its lower resolution, as compared to both of the Skylab camera systems.

It is somewhat surprising that S-190B color did not rate higher in this test. A possible explanation is that, for point identification of image types (where mapping decisions are not involved) the higher resolution of both the S-190B and S-190A color is unimportant. It is likely that had we used color infrared film in the S-190B camera, its interpretability score would have been substantially higher (see section on mapping experiments where S-190B color and S-190A color were both found superior to LANDSAT-1 and S-190A color infrared imagery).

In the Colorado Plateau area, LANDSAT-1 color reconstitution proved inferior to both S-190B color and S-190A color at a highly significant level. S-190B color was superior to S-192 at P=0.90. No other differences approached significance in the Colorado Plateau test. The reason for poor performance in the Colorado Plateau region may be the season of imagery used. For the low elevation arid types, it was peak green. Differentiations between sagebrush and salt desert were somewhat difficult and images were particularly variable because of soil type variation. At the intermediate elevations oakbrush was in full leaf and tended to override associated juniper and ponderosa pine when the latter were in open stands. At the high elevations, vegetation was still dormant so that poor discriminations were provided between aspen and meadow types and between oakbrush and aspen stands where the former fingered up into the higher elevations.

Commission-omission error analysis: A standard commission-omission error comparison was also performed on the Test Two data (Table XIV). The Sierra-Lahontan study (those most consistently significant in comparisons among image types) gave essentially the same results as the more comprehensive Test One, insofar as color imagery is concerned.

From the Colorado Plateau test area, LANDSAT-1 data ranked poorest of all on the basis of "total percent correct" and interpretations and commission errors, although differences were small and few of them significant. The best results were obtained for this region with S-190B color, both on the basis of total correct and the number of commission errors; although in these instances we are talking about apparent differences, none of which would be found significant at reasonable probability levels. On the basis of commission errors, a suggested ranking of S-190B best and LANDSAT-1 with S-192 poorest is suggested by the Colorado Plateau data; and LANDSAT-1 best with S-190A color, S-190B color, and S-192 poorest in the Sierra-Lahontan region (Table XIV).

If these data were combined for all groups and regions, the combined magnitude of error and compensating differences resulted in essential non-significance. Only S-190A color infrared and LANDSAT-1 color reconstitutions were significantly better than S-192 (P=0.99 and 0.95, respectively). A more specific explanation may be that some of the images, particularly LANDSAT-1, were far superior for the Sierra-Lahontan than for the Colorado Plateau. In the Colorado Plateau the LANDSAT-1 image was uniformly red to pink for many vegetation types, whereas they were strongly contrasting in Sierra-Lahontan. The same can be said of the S-190A color infrared, although the problem was not as bad as with LANDSAT-1 data in the Colorado Plateau.

These results further support a practical guideline that our accumulated experience has suggested--namely, the best season for imaging natural vegetation with color infrared is as the vegetation types of interest are moving into the dry or mature season. The interpretability of many types of natural vegetation is nearly always low during the peak green season.

In making these statements one must not minimize the importance of the multidate imaging capability of the LANDSAT-1 system. Both for full visual and machine-aided, interactive interpretation of space imagery, the multidate component is the only way some identifications can be made with reliability (Figure 8 and 9).

The most specific statement that can be made from this series of comparisons is that LANDSAT-1 and S-190A color infrared are the superior image types when the capability of interpreters to correctly identify point images is the criterion for judgment, and that LANDSAT-1 over S-190A color infrared seems to be favored. As support imagery the S-190B shows some points of advantage; and, had we the opportunity to test S-190B color infrared, it might well have been higher in the scale assuming adequate photo quality control and consistency. In addition, the black-and-white infrared showed advantages in selected discriminations and thus should be considered in a support role for visual interpretation.

It should also be recognized that S-192 is really a finer-tuned multispectral system than LANDSAT-1 and it is unfair to compare it in photographic mode. We were asked specifically to include the 1, 7, 9 color reconstitutions in our visual interpretation testing. For lack of funds and time after receipt of S-192 tapes, we were unable to include it in the digital analysis format where it might well have performed superiorly if our parallel experience with LANDSAT-1 digital data can be taken as an indication of what to expect.

In considering these results as well as in designing new and further experiments, it is important to recognize that only point identification, not mapping, of natural vegetation analogs was tested in the previous experiments. This is only half of the mapping job. Delineation capability must also be assessed. The final "proof of the pudding" is, however, in identification because there are workable alternatives for minimizing problems of delineation.

Kinds of commission errors.- In a combination of data from Tests One and Two, we considered the interpretability of specific analogs in terms of the kinds of confusion involved in the commission error categories. We established a threshold level of two commission errors per ten decisions on a single vegetation analog category as the possible confusion level above which special training and care would be required or justified to minimize commission errors in interpretation. There is a significant analog-image type interaction. Thus the best image type is a function of the subject of interest (Table VII).

The next table (Table XV) summarizes the problem analogs based on the above-mentioned threshold concept. For this summary and analysis the results of Tests One and Two were combined and the combined results presented in Table XV. Observe that

341.1, pinyon-juniper; 341.2, ponderosa/Jeffrey pine; 347, mountain brush or chaparral; and 315, meadows are the problem analogs on which training and care of interpretation should concentrate.

Mapping Experiments

Mapping experiments are most difficult to conduct because any map is a generalization of reality and to a large degree the result is subject to the individual interpretation of mapper who must decide:

1. How to resolve gradients and intricate patterns with the legend system,

2. How to compromise these same patterns with a mapping intensity or level of generalization appropriate to the purposes for which the map is being made, and

3. When to ignore certain features as unimportant inclusions.

Except in the case of pure, distinct types that clearly exceed the minimum "intensity of delineation" standards, it is rare that any two experienced individuals will produce exactly the same map. If they correctly identify the subjects delineated within each boundary and reasonably assess the proportions of each within that boundary, their differences in delineation are inconsequential--who is to say which map is correct and which is in error. If these decisions by the interpreter are accurate (identification and proportion of area), the data tabulation for all interpreters will add up to the same set of statistics regarding the kinds and amounts of features being mapped.

In the Sierra-Lahontan region we found it necessary to use widely diverse areas to get a representation of the necessary analogs while we could achieve this in a single transect of approximately 1,761 square kilometers in the Colorado Plateau region. All mapping experiments and comparisons were done in the latter region for this reason.

A set of mapping guidelines was followed in delineation and annotation (Appendix B1). As each delineation was made its components were tallied on a standard form (Appendix B2) along with time expended notations. Delineation was done on the combined basis of vegetation and land surface features so that identification provided both components of the legend. The key results of all this work are presented in the tables and discussion that follow.

<u>Image types discernible on each kind of image</u>.- One of our first experiments was to determine the number of kinds of images that could be discerned on each image type without regard to identification of the subjects represented. Such a test is meaningful and valid on the assumption that if one can discern a difference and thus delineate a subject area, there are many ways by which it can be accuaretely identified to provide useful information.

To make this comparison, an identical area of approximately 21-square inches was laid out on each image type. From this population, six one-square-inch samples were drawn. To provide direct comparability, the same six locations were used for each image type. Two experienced interpreters examined each square-inch sample and independently decided on the number of image classes that could be discerned within the designated sample area. They first did the "easy to discern" determination, compared results and discussed differences to agree on the number that their collective experience indicated could be repeatedly detected without problems of incomplete boundary location and consistency of recognition. This number was entered as the first observation for the square-inch sample area. They then repeated the process to decide on the total number

of image classes that could possibly be discerned in the same sample area by considering subtle differences in density, color, or image texture. Notes were compared and a single decision again reached on the maximum number that could be practically interpreted in an operational setting; i.e., entire boundary definable and reasonable expectation that interpreters, working under the same set of mapping intensity guidelines, would be able to recognize each image type.

The average number of classes discerned in the six square-inch sample areas is tabulated in descending order by film type in Table XVI.

These data enable a comparison of color versus black-and-white; for the "easy discernability" class color defined, 38 percent more kinds of images than black-and-white and 50 percent more for the "total possible" class. In this case note that S-190A color infrared and S-190B color were superior and that S-190A black-and-white red band was third even though in the identification testing this image type was either poorest or next to poorest image type. LANDSAT-1 color reconstitution was fourth; and while the infrared black-and-white images proved out well in the identification tests, they were rated on the bottom in terms of discriminating power.

Comparative results of mapping.- The comparative results of mapping provide a guide to the better image types in two ways: First, from information relevant to the amount of extractable information; and second, on the basis of costs of deriving the information. Table XVII summarizes the data relevant to these questions for each image type when mapped at the constant scale of 1:250,000.

Note first that LANDSAT-1 provided the highest percentage of "pure types," but this may be due to the higher level of generalization inherent in the poorer resolution of the image used and season of acquisition. The other image types are essentially the same as regards this indication of mapping intensity. The highest percentage of 3-way complexes mapped was from the highest resolution image types, S-190B color and S-190A color infrared. In the former case the percentage was high (14 percent) because of resolution of the system. In the second case it was high (13 percent) because of the increased detectability of certain types resulting from the infrared band and the false color product. The other high percentage of 3-way complexes was mapped on the Uncompahgre Plateau example of the S-192 color data. Here the reason was due to our mapping this example from 1:79,000 scale material and the fact that this image was particularly good in terms of vegetation type resolution. We were able to see and identify far more kinds of vegetation than could be mapped at such a small scale.

The average boundary scores favored S-190A color and S-190B color with S-192 color averaging lowest. The number of delineations per 2,000 square kilometers is also an index of information content when mapping is done under the same standards. This tends to place S-190B color at the top, S-190A color and color infrared intermediate, and LANDSAT-1 and S-192 at the bottom in that order.

Cost factors are, of course, a function of the number of delineation and identification decisions that have to be made and how easily they can be arrived at. When imagery is poor, and of its nature generalizes the ground features, costs tend to be low but cost per unit of information may be high. Similarly, S-190B color looks very expensive in man-hours and S-190A color infrared more expensive than LANDSAT-1. If, however, one ratios the cost to information on the assumption that number of delineations per 2,000 square kilometers is an index of information content, the image types line up as follows:

Image Type	Ratio
S-190B color	0.50
S-190A color infrared	0.42
LANDSAT-1	0.43
S-192 color	0.30
S-190A color	0.30

There are, of course, other criteria of benefit and value. Without considerably more work it is difficult to determine which system the cost benefit really favors--except to recall that the two intermediate cost systems (S-190A color infrared and LANDSAT-1 4, 5, 7 color) were nearly always on top in accuracy of identification. These two systems also came out top and intermediate, respectively, in the discriminating power study (Table XVI). These facts would strongly tend to throw the cost benefit in their favor because of the higher reliability of the information derived--since the proof is in reliability of information, not delineation density.

Accuracy of identification in mapping.- It was our original intention to use the high-flight RC-8 color infrared photography as a standard for judging the accuracy of both mapping and identification by the space imaging systems. This did not prove too successful because of the difficulty of deciding how best to generalize between the aircraft and the space systems and because we did not encounter enough examples of some types within the test belt of superimposed imagery to provide a sufficient sample size. However, for one second order, one third order, and four fourth order analogs, we were able to make a reasonably good comparison. This comparison for two strongly contrasting image types, S-190B color and LANDSAT-1 is presented in Table XVIII. In both cases we expected the accuracy at second and third level to be higher than at fourth level. This was true only for the S-190B color, not for LANDSAT-1. For all but the 320 (shrub/scrub) class, accuracy levels are quite acceptable, being lowest for 341 (coniferous forest). The 320 class was low because this is one of the most difficult classes in this particular region to discriminate. There was a strong tendency to confuse 320 with some of the 341 types. This may also be what pulled down the 341 accuracy. More importantly, these results show that space imagery can be interpreted to fourth level in some instances if the interpreter knows what to expect in the area. Had the area allowed a comparison of 324 (salt desert), 325 (shrub steppe), and 327 (macrophyllous shrub), it is our hypothesis from other interpretation work in the project that satisfactory results would have been obtained--especially had it been possible to incorporate multidate imagery and to evaluate the areas in stereo.

Stereo Interpretation from Space Imagery

Since our first successful experience with the stereoscopic interpretation of Apollo VI photography over southern Arizona, this author and many of his associates have been proponents for the use of stereoscopic interpretation of space imagery whenever possible. Upon our request, most of our Skylab imagery was taken with 60 percent forward lap, and we had done side lap stereo interpretation of LANDSAT-1 data in the early phases of that experiment. Routinely in our operational project work, we make use of the side lap area between orbits as a starting point in visual image interpretation of LANDSAT-1 data.

Our first experiment in stereoscopic interpretation was conducted with inexperienced students in connection with Identification Test One. In this experiment, ten of the interpreters were given a stereoscopic identification test of point data in the Colorado Plateau Test Region as a repeat of the monoscopic test they had taken some weeks earlier. The long delay was intended to compensate for any familiarity bias in the second stereoscopic test. S-190A color infrared images were used for the test. The working materials were enlarged to the point that the images would be at approximately the same scale when viewed under a magnifying stereoscope as the monoscopic images when viewed without magnification.

The following overall results were recorded for the ten interpreters: monoscopic interpretation, 82.7 percent; stereoscopic interpretation, 77.3 percent. The two sets of data were not significantly different when subjected to a paired "t" test (P=0.99). Two reasons are offered in explanation: (a) although the students had unimpaired

stereo vision, none had had significant experience with stereoscopic interpretation; and (b) more importantly, none of the students were experienced in relating vegetation to its physical setting--they just did not know what to expect. The illustrated introduction to the natural vegetation was apparently inadequate to prepare them for interpretation of the stereoscopic model.

To assess whether the results of a trained interpreter might be better than those of the student group, one of the investigators took the same test. This individual had had extensive stereoscopic viewing experience and understood the relationships between vegetational zonation, landform, and elevation. His results are summarized below:

Category	Number of Correct Responses (maximum = 10) Monoscopic	Stereoscopic
J - Pinyon-juniper	6	10
P - Ponderosa pine	8	10
W - Carex meadows	9	7
A - Aspen	7	10
S - Spruce-fir	5	7
X - Other vegetation types	5	7

Pronounced improvement in identification accuracy was noted for all categories but one. This category--sedge meadow (W)--always occurs in very small units and was sometimes difficult to see clearly on the stereo model. This limited comparison highlights the important role to be played by a trained interpreter when extracting image information from a complex landscape. Knowledge of the ecological relationships present in that landscape is essential to accurate interpretation. Under these circumstances, it was our hypothesis that stereoscopic interpretation will produce markedly improved results over monoscopic interpretation.

In connection with the more comprehensive mapping experiments, we set about to test this hypothesis.

Stereoscopic evaluation of ground resolution.- Each image type was viewed at two scales for this test. Four kinds of a natural resolution target were evaluated for clarity (++ = very clear or obvious; + = evident; - = not evident). These were converted into a numerical score as shown in Table XIX. The S-190A color and S-190B color were best and the only place where stereoscopy gave an advantage was in some of the linears.

Stereoscopic perception of relief change.- We next set about to determine what magnitude of relief differences a person with good stereo perception could actually see as a three-dimensional model with each kind of space imagery. Side lap stereo was used for LANDSAT-1. All of the features listed in Table XX were scored by the same method as the ground resolution targets and numerical scores were computed in the same way. This showed S-190B color superior to other systems. On S-190A color and the S-190B one could see relief differences as slight as 200 feet. The perception of relief was a function of the rate of change but even in relatively level to rolling macrorelief, one could see a true stereo model down to a threshold of 200 to 225 feet per mile. This perception capability is highly important and of great value in identification of vegetation analogs through relationship to landform, slope, and position on slope. While conducting this test it was evident that under certain conditions monoscopic viewing could give a depressional perspective when in fact one was looking at strongly hilly macrorelief. Such misconceptions of landform did lead to identification errors of substantial magnitude--for example, erroneously calling deciduous aspen and mountain meadows sagebrush steppe and salt desert vegetation types when viewed monocularly.

Stereoscopic improvement of identification decisions.- By reassessing monocular mapping and identifications of both vegetation and landform features in the same 1,761 square kilometer area of each imagery type except S-192, we were able to make a good assessment of the benefits from stereo interpretation. Table XXI shows the amount of delineation and identification change made by stereo examination at a scale of 1:250,000. This table suggests that there are important differences among imagery types as regards the benefit from stereo viewing. More changes in boundary were made with LANDSAT-1 and S-190A color than with the other imagery types. Many of these boundary changes were of substantial areal significance. Most of them were made either in areas of undulating to slightly hilly macrorelief or in areas where the image characteristics gave the impression of gentle relief when in fact the subject was strongly hilly to mountainous. This is particularly helpful in the case of isolated buttes and small mountain systems. Also in the gentler relief areas one can relate a vegetation change to a break in relief when such is impossible in mono viewing. The changes in identifications were substantial for S-190B color.

The low contribution of stereo to S-190A color infrared is probably due to the poor resolution characteristics of the particular image used in this experiment. The large number of changes in landform classification with the S-190B color when viewed in stereo is most likely due to its higher resolution and the fact that by viewing in the stereo model, more of the features of relief can be seen and more of the vegetation pattern explained.

We next looked at the exact nature of the changes in identification resulting from stereoscopic viewing. These comparisons are shown in Table XXII. Part of the change in the 2.3 class was the result of calling the lands more flat in mono interpretation and to the changes in the hilly and mountainous classes. Changes were made from hilly to mountainous. A stereo classification into mountainous of some of the lands formerly considered in class 2.3 accounted for some of the large differences between mono and stereo identification. Some of the mountainous relief difference could not be judged by monocular interpretation.

Much of the change in 130, rockland, resulted from being better able to perceive mountainous rocklands in stereo. The perception of lowland flatlands contributed to some of the change into 310, herbland, classifications. Most of the change in 327, macrophyllous shrub, and 341, coniferous forest, resulted from being better able to define the true 327 areas in stereo since they are higher plateau and hill land related. There was a tendency to overestimate 327 where it occurred adjacent to 341 and particularly to underrate the latter where stands were open. Some of these errors were corrected by landform relationship in stereo viewing. While one could not see individual conifer trees, the 341.3, mixed conifer, class could be much more accurately identified in stereo because of the strong relationship to steep slopes, valleys, and high hill and mountain positions that this type occupies.

While more in-depth studies by larger numbers of experienced interpreters could refine and improve upon measurements of value from stereo, we feel that these results are sufficient to stimulate more serious consideration in use of stereoscopic interpretation of space imagery where natural vegetation and soil conditions are the main points of concern.

AN OPERATIONAL SYSTEM FOR EARTH RESOURCE ASSESSMENT

One of the author's goals from the beginning of his involvement in the Earth Resources Space Applications Program has been to devise or suggest an effective operational system for amalgamation of space and aircraft remote sensors into an efficient and cost-effective operational system for inventory, analysis, and monitoring of earth

resources and land use. While some may feel we haven't yet arrived, the facts are that, since early in the LANDSAT-1 program, Earth Satellite Corporation has been using space and aircraft image· in combination and alone when appropriate, to service the needs of clients on three continents and in all disciplines in a cost-effective way. The following flow diagrams and discussion do not necessarily reflect the unified opinion of the company. It is the author's expectation, however, that high agreement in principle and on the general concept will prevail throughout the remote sensing community. Most disagreement among those of us with substantial experience in space systems applications would probably be in the area of details and adaptation of this kind of general pattern to specific cases. At least the author is willing to take full responsibility for the commendable qualities and deficiencies of the following ideas with the hope that this presentation will stimulate criticism and a focusing of energy on the true problems of a cost-effective, operational space and aircraft system so that the benefits of space technology can more effectively serve the needs of mankind.

A highly generalized flow diagram is presented in Figure 10. The details represented by each of its blocks are then expanded in Figures 10a, 10b, 10c, and 10d.

The generalized flow diagram of Figure 10 is essentially self-explanatory, but a few points may require clarification. A ground truth mission is scheduled deliberately relatively early in the flow chart. In practice ground truth missions come into the system at many points. It is better to emphasize their role by inclusion in the direct flow-line rather than to de-emphasize such an important component by placing it in a multi-focused peripheral loop. The first ground truth mission, in a reconnaissance mode, may actually have to be performed as a part of the background work in some projects. It can be a part of any subsequent stage through "refined interpretation."

This generalized flow diagram emphasizes another important concept--namely, that the first-cut interpretation is done most effectively by knowledgeable and experienced interpreters. This is in contrast to the viewpoint of some who feel that "because of the magnitude of data in wide-area synoptic coverage, the first interpretations must be by machine." Accumulating experience and demonstrated ability to do these first-cut interpretations rapidly, efficiently, and adequately by visual interpretation leads this author strongly to challenge the wisdom and particularly the cost effectiveness of doing these first-cuts by computer analysis.

Finally, in the generalized treatment, the role of "feedback" deserves some special attention. Almost without exception in the operational mode, feedback may start at any stage beyond the initial stratification to bring about refinements, to improve adaptation to the specific problem situation, and to enhance performance. Feedback is, of course, particularly important when one reaches the monitoring component of the "decision and action" block. Now let us look within these blocks at some important details and alternatives.

Some of the major components of background work are specified in the expanded flow diagram of Figure 10a. The various functions in this unit should be self-evident but disregarding or side-stepping of important components in this stage sometimes jeopardizes successful application of the system.

The block representing those factors of design, classification, intensity, and repeatability also includes the idea of adopting the legend system. Following are the main advantages of the legend system we have devised and perfected by diligent modification and testing plus sessions to seminar and critique the legend by people actively involved in practical operational use of the system. It has gone through numerous revisions and extensive field verification. The legend has evolved into its present form demonstrating its practical usefulness for application to space and high-flight image analysis after having a rigorous and critical development process. The main advantages of the system are:

1. It is based on divisive logic that is consistent with a growing understanding of earth resources and upon consistent criteria for differentiation by visual stimuli among classes at each hierarchical level.

2. It accommodates in a single coherent system the natural vegetation, vegetation modified by intent with a permanent management goal, barren lands, all water resources, as well as those land-uses that have permanently altered the nature of the earth's surface, i.e., urban, industrial, transportation, and utility distribution, and extractive industries.

3. By being ecologically rather than urban-industrially orientated, it characterizes the landscape features on a natural basis that is free of land-use bias.

4. The system thus provides a superior basis for treating the multiple land-uses so common in the "wildlands" situation such as the case where the same piece of land is used for forestry, range, watershed, wildlife, and recreation. To knowledgeable resource ecologists, these potentialities for use are often self-evident in the description that the legend system gives of specific landscapes.

5. It is numerical and thus highly computer compatible.

6. It is conceived on a consistent logic through the fourth, fifth, and even to the sixth hierarchical level.

7. It allows easy and consistent agglomeration from the finest to the most generalized category.

The initial stratification stage (Figure 10b) is largely determined by the nature of the problem being attacked and the information needs being met through remote sensing. For problems where a regional perspective is needed or a land-use interrelationship picture is to be portrayed, space imagery is often ideal. For some problems however, the initial small-scale, stratification stage may best be performed on high-flight aerial photography. In the initial stratification stage it is also important to emphasize the need to do ground truth and over-flight missions with imagery in hand.

Especially when working with space imagery the first two intensity levels of stratification should consider the appropriateness of an ecological province (or subregion) breakdown followed by a second-order stratification into land systems after the technique that is widely used in Australia. Following this, the third-order stage is delineation into appropriate levels of an hierarchical legend system similar to the one we have devised and proven through extensive use. For some projects this latter will represent the first order of stratification.

One of the most important features or concepts of space and high-flight image application is exemplified in the "prioritized areas" function of the initial stratification stage. By the application of these techniques, one quickly defines the areas of no concern so that all energy at an early point is focused on those important landscapes that are truly relevant to the problems at hand. This feature is a great saver of dollars and both scientific and managerial manpower.

In the second subsampling stage (Figure 10c) one moves to larger scale and/or finer resolution, and machine-aided, interactive interpretation becomes appropriate if not essential for maximum effectiveness of the system.

Strong emphasis should be placed on "support system selection and staging." At this point, the results of research similar to those reported here become paramount

in making the proper choices among operational support systems. The author's own accumulated experience to this point strongly suggests that, if space imagery is appropriate as the initial stratification stage, the LANDSAT MSS system is ideal for such applications. Supporting this system then, in the second subsampling stage, one has at least four highly viable options. Remember that this stage follows the prioritizing of areas of concern. Within these areas then, the options become first, digital analysis of MSS data similar to LANDSAT-1 or possibly, with de-bugging and refinement, systems like the S-192. A second option which we in Earth Satellite Corporation are beginning to use extensively is the special enhancement and reprocessing of LANDSAT-1 data from the magnetic tapes to produce an improved photographic product at scales from 1:400,000 to 1:100,000. These images can be somewhat "tuned" to the needs of second-level analysis in areas of critical concern. A third option is use of special space systems such as the Skylab S-190B where higher resolution is needed because of the nature of problems being addressed.

A little-used option with high potential is visually interpreting stereo imagery from space, and still another option employs multidate or multi-season imagery. This requirement is another strong point in favor of an un-manned system such as LANDSAT-1 as the basic earth resource monitoring system. When one considers the practical problems encountered in getting a desired set of multidate imagery, superimposed over a clearly defined pair of interregional test sites, the advantages of a continuous running or programmable sun synchronous system can be easily demonstrated. While, for natural vegetation applications, nine-day frequency of repeat coverage will rarely if ever be needed, there were many times during our LANDSAT-1 and Skylab experiments when a nine-day repeat cycle would have given us imagery we critically needed. Slippage of nine days around a critical stage of plant development can usually be tolerated, 18 days often not.

Finally, but certainly not of least importance, conventional aerial photography in a multistage mode will always have a role to play in any comprehensive earth resources inventory and monitoring system that has as one of its goals contribution to resource management The scale and spatial resolution of systems used under this option are highly dependent on the kinds of problems addressed. For example, if the solution of rangeland resources problems is approached with the intent of fully capitalizing on remote sensing capability, certain components of the problem require imagery at larger scales of 1:1,000 or 1:600 and with stereo overlap. These needs can hardly be met from presently available,civil applications space technology. At the present time it is the author's feeling that, while digital analysis of LANDSAT MSS data can be effectively done at a quasi scale of approximately 1:24,000 looking at 0.4 hectare units of land, this multispectral system cannot meet all of the requirements for assessing many natural vegetation management and soils stability problems.

Having selected the appropriate support systems and designed a multistage approach compatible with the problem situation, refined interpretation moves ahead to produce both certain and uncertain inventory decisions. A ground truth mission comes back into the loop as the uncertainties are removed or reduced to a tolerable level.

The product development block (Figure 10d) is an integral part of the remote sensing application package in the context of map preparation, derivation of statistical sets of necessary data and the interpretations that give the data and maps relevance to the problems to be solved. These actions lead to reports and recommendations that carefully address the problem. This ensures that the real "proof of the pudding" can be realized in a rational decision and action program--one that is effectively monitored to fine tune and adjust the program and ensure complete success in problem solving.

To the question, "Is such an operational program feasible?" we merely respond that Earth Satellite Corporation is now using LANDSAT-1 data, and in some cases Skylab

imagery, together as appropriate with aerial photography for solving real problems. Such applications have taken place in the United States and on at least two continents other than North America. Many of the ideas embodied in the above flow diagram have been field tested in these kinds of operational projects. In this writer's opinion, space-born remote sensing systems have already been proven operational. A significant number of projects are now moving ahead in developing nations and other where the resource base is not well understood with a speed and at a cost that could not be approached--in some cases not even considered--if we lacked the option of doing the first-phase analysis by the interpretation of space imagery.

REFERENCES

[1]Poulton, Charles E., Barry J. Schrumpf, and Edmundo Garcia-Moya. 1971. A Preliminary Vegetational Resource Inventory and Symbolic Legend System for the Tucson-Willcox-Fort Huachuca Triangle of Arizona. In Colwell, Robert N. (ed.). Monitoring Earth Resources from Aircraft and Spacecraft. National Aeronautics and Space Administration. Sci. and Tech. Info. Office. Washington, D.C. NASA SP-275. pp. 93-115.

[2]Poulton, Charles E. 1972. A Comprehensive Remote Sensing Legend System for the Ecological Characterization and Annotation of Natural and Altered Landscapes. Proceed. Eighth International Symposium on Remote Sensing of Environment, 2-6 October 1972. Willow Run Laboratories, Environmental Research Institute of Michigan, Ann Arbor. pp. 393-408.

[3]Legge, Allan H., et al. 1974. Development and Application of an Ecologically Based Remote Sensing Legend System for the Kananaskis, Alberta, Remote Sensing Test Corridor (Subalpine Forest Region). International Society for Photogrammetry, Banff, Alberta, Canada. 7-11 October 1974.

[4]Results published in a special technical report to NASA, "A Comparison of Skylab and ERTS Data for Agricultural Crop and Natural Vegetation Interpretation." By Earth Satellite Corporation. July 1, 1974.

Table I.- Types and Dates of Imagery Used in the Two Test Regions

System/Film	Date	Area
LANDSAT-1 CIR	May 18, 1973	Colorado Plateau
S-190A/CIR	June 5, 1973	Colorado Plateau
S-190A/Color	June 5, 1973	Colorado Plateau
S-190B/Color	June 5, 1973	Colorado Plateau
S-192 (1,7,9) Color	Aug. 4, 1973	Colorado Plateau
LANDSAT-1 CIR	July 25, 1973	Sierra-Lahontan
S-190A/CIR	Aug. 11, 1973	Sierra-Lahontan
S-190A/Color	Aug. 11, 1973	Sierra-Lahontan
S-190B/Color	Aug. 11, 1973	Sierra-Lahontan
S-192 (1,7,9) Color	July 25, 1973	Sierra-Lahontan

TABLE II.- THE IMAGE TYPES EVALUATED IN THE FIRST AND SECOND SERIES OF INTERPRETATION TESTS

First Test	Second Test
LANDSAT-1 Color Composite Band 5 B/W Band 7 B/W	LANDSAT-1 Color Composite
SKYLAB, S-190A Color Infrared Color Red Band B/W Infrared Band B/W	SKYLAB S-190A Color Infrared Color
SKYLAB S-190B Color	SKYLAB S-190B Color
	SKYLAB S-192 Color Composite

TABLE III.- CRITERIA FOR RATING THE EASE AND CERTAINTY OF DELINEATING BOUNDARIES

Rating 1.	Boundary line easy to decide, clear, and distinct.
Rating 2.	Boundary delineation presents some problems, some area of diffuse boundary but mostly fits condition 1.
Rating 3.	Boundary definition has some alternatives; specifically, half or more of boundary shows diffuse change, thus allowing for different interpretations of where the boundary should fall. However, for any of these alternatives, differentiation definitely appears stronger after line is drawn. Line is not significantly arbitrary.
Rating 4.	Boundary definition is quite arbitrary, likely to be made with marked difference by different people; only small portions of boundary (<30%) are distinct as in 1, 2, or 3.

TABLE IV.- CRITERIA FOR RATING THE IDENTIFIABILITY OF IMAGES

Rating 1.	Positive; little likelihood of identification errors.
Rating 2.	Reasonable certainty; probably a few inconsequential identification errors.
Rating 3.	Moderate chance of error; identification highly dependent on associated convergence of evidence or local familiarity.
Rating 4.	Substantial chance for error; attempted identification is little better than a guess.
Rating 5.	Inadequate information to identify; no identification.

TABLE V.- ANALOGS USED IN INTERPRETATION TESTS ONE AND TWO

Numeric Symbol	Vegetation Type	Alpha Symbol	Used in Test	
			One	Two
315	Meadows	W	√	
325.1	Sagebrush	Sa		√
341.2	Ponderosa/Jeffrey Pine Forest	P	√	√
341.1	Pinyon-juniper Woodland	J	√	√
341.4	Spruce-fir	S	√	
342.4	Aspen	A	√	
347	Oakbrush/Mountain Chaparral	B		√
	Other Vegetation Types	X	√	√

TABLE VI.- RANKING OF IMAGES IN DECREASING

ORDER OF INTERPRETABILITY

Image Type	Overall Average Correct Responses (All crop categories)[1/]
EREP S-190A Color IR	7.9
LANDSAT-1 Color Composite	7.0
EREP S-190B Color	6.4
EREP S-190A B/W IR	6.4
LANDSAT-1 Band 7	6.2
EREP S-190A Color	5.5
EREP S-190A B/W Red	5.2
LANDSAT-1 Band 5	4.6

[1/] Maximum possible value = 10. Test is by Tukey's method of pairwise comparison.

TABLE VII.- ANALYSIS OF TEST DATA

(NATURAL VEGETATION IDENTIFICATION TEST)

RANKING OF IMAGE TYPES BY COMMISSION ERROR

For each of the natural vegetation categories listed below, the image type(s) are given which form a group that is significantly different from all others in terms of commission error (using Tukey's method of pairwise comparison). These images are those for which commission errors are lowest.

Natural Vegetation Category	Image Type
Pinyon-juniper	EREP S-190A Color IR
Ponderosa pine	EREP S-190A Color IR
Sedge meadow	EREP S-190B Color
Aspen	EREP S-190A Color IR EREP S-190A Color EREP S-190A B/W IR
Spruce-fir	EREP S-190A Color IR EREP S-190A B/W IR ERTS Color Composite
Other natural vegetation	EREP S-190A Color IR EREP S-190A B/W IR EREP S-190B Color

TABLE VIII.- COMPARATIVE INTERPRETATION ERRORS BY IMAGE TYPE

FROM TEST ONE (2400 DECISIONS)

Image Type	Percent Correct	Percent Commission Errors	
		Range in %	$\bar{x} \pm SE_{\bar{x}}$
LANDSAT-1 Color	71	11-43	30.33 ± 5.02
LANDSAT-1 Band 7	62	16-58	37.33 ± 6.81
LANDSAT-1 Band 5	46	44-67	53.50 ± 3.50
S-190A CIR	78	10-26	21.51 ± 2.81
S-190A Color	55	35-50	44.7 ± 2.11
S-190A B/W IR	64	12-56	35.8 ± 7.01
S-190A B/W Red	52	42-57	48.7 ± 2.67
S-190B Color	65	18-46	33.3 ± 4.59

TABLE IX.- SIGNIFICANCE OF DIFFERENCE MATRIX

COMPARING IMAGE TYPES FROM TEST ONE

Image Type	LS-1 Color	LS-1 B-7	LS-1 B-5	S-190A CIR	S-190A Color	S-190A B/W IR	S-190A B/W Red	S-190B Color
LS-1 Color	X							
LS-1 B-7	7.06	X						
LS-1 B-5	** 13.17	+ 16.17	X					
S-190A CIR	8.83	+ 15.83	*** 32.00	X				
S-190A Color	* 14.37	7.37	+ 8.80	*** 23.20	X			
S-190A B/W IR	5.47	1.53	* 17.70	+ 14.30	8.90	X		
S-190A B/W Red	** 18.37	11.37	4.80	*** 27.20	4.00	12.90	X	
S-190B Color	2.97	4.03	*** 20.20	+ 11.80	* 11.40	2.50	* 15.40	X

TABLE X.- PERCENT CORRECT INTERPRETATION BY TEN INTERPRETERS

FOR FIVE IMAGE TYPES IN TWO REGIONS

Group	Interpreter	Colorado Plateau					Sierra-Lahontan					
		192	190B COLR	190A COLR	190A CIR	LS-1		192	190B COLR	190A COLR	190A CIR	LS-1
1	H	79	80	92	84	76		48	52	56	64	92
	M	63	76	68	68	60		56	68	84	84	92
	O	67	52	48	60	44		56	76	60	80	88
	S	58	76	72	60	56		60	68	60	72	80
	V	67	84	84	84	60		60	64	60	80	92
	$\bar{X}$	66.8	73.6	72.8	71.2	59.2	$\bar{X}$	56.0	65.6	64.0	76.0	88.8
	$SE_{\bar{X}}$	3.47	5.60	7.53	5.43	5.12	$SE_{\bar{X}}$	2.19	3.92	5.06	3.58	2.33
2	C	54	80	88	76	68		68	52	64	68	68
	Ho	79	72	80	80	48		76	72	64	80	92
	L	67	88	76	80	80		60	56	60	76	100
	P	63	84	68	56	60		64	64	60	72	88
	Vo	79	72	72	72	64		64	52	48	72	80
	$\bar{X}$	68.4	79.2	76.8	72.8	64.0	$\bar{X}$	66.4	59.2	59.2	73.6	85.6
	$SE_{\bar{X}}$	4.81	3.20	3.44	4.45	5.22	$SE_{\bar{X}}$	2.71	3.88	2.94	2.04	5.46
GRAND $\bar{\bar{X}}$		67.6	76.4	74.8	72.0	61.6		61.2	62.4	61.6	74.8	87.2
	$S_{\bar{\bar{X}}}$	2.81	3.18	3.96	3.32	3.54		2.39	2.81	2.87	1.98	2.85

TABLE XI.- SIGNIFICANCE OF DIFFERENCE MATRIX COMPARING IMAGE TYPES BY GROUP I INTERPRETERS IN THE SIERRA-LAHONTAN REGION

Image Type	192	190B Color	190A Color	190A CIR	LS-1
192	X				
190B Color	9.6	X			
190A Color	8.0	1.6	X		
190A CIR	** 20.0	+ 10.4	12.0	X	
LS-1	*** 32.8	** 23.2	** 24.8	$\underline{*}$ 12.8	X

LEGEND:

*** = Very highly significant, greatly exceeding P=0.99

** = Significant at P=0.99

$\underline{*}$ = Significant at P=0.98

* = Significant at P=0.95

+ = Significant at P=0.90

TABLE XII - SIGNIFICANCE OF DIFFERENCE MATRIX COMPARING IMAGE TYPES BY GROUP II INTERPRETERS IN THE SIERRA-LAHONTAN REGION

Image Type	192	190B Color	190A Color	190A CIR	LS-1
192	X				
190B Color	7.2	X			
190A Color	7.2	0	X		
190A CIR	+ 7.2	$\underline{*}$ 14.4	** 14.4	X	
LS-1	$\underline{*}$ 19.2	** 26.4	** 26.4	+ 12.0	X

LEGEND:

*** = Very highly significant, greatly exceeding P=0.99

** = Significant at P=0.99

$\underline{*}$ = Significant at P=0.98

* = Significant at P=0.95

+ = Significant at P=0.90

TABLE XIII.- SIGNIFICANCE OF DIFFERENCE MATRIX COMPARING

IMAGE TYPES BY GROUPS I AND II INTERPRETERS

IN THE COLORADO PLATEAU REGION

Image Type	192	190B COLR	190A COLR	190A CIR	LS-1
192	X				
190B COLR	8.8+	X			
190A COLR	7.2	1.6	X		
190A CIR	4.4	4.4	2.8	X	
LS-1	6.0	14.8**	13.2**	10.4	X

LEGEND:

*** = Very highly significant, greatly exceeding P=0.99

** = Significant at P=0.99

$\underline{*}$ = Significant at P=0.98

* = Significant at P=0.95

+ = Significant at P=0.90

TABLE XIV.- COMPARATIVE INTERPRETATION ERRORS BY IMAGE TYPE

FROM TWO REGIONS, TEST TWO (1,250 DECISIONS)

Image Type	Percent Correct		Percent Commission Errors			
	Colorado Plateau	Sierra-Lahontan	Colorado Plateau		Sierra-Lahontan	
			Range	$\bar{x} \pm SE_{\bar{x}}$	Range	$\bar{x} \pm SE_{\bar{x}}$
LANDSAT-1 CIR	62	87	20-45	36.8 ± 4.06	0-21	12.7 ± 2.79
S-190A CIR	72	75	13-36	27.5 ± 2.26	6-34	24.4 ± 3.11
S-190A Color	75	62	16-40	28.9 ± 5.39	11-68	39.5 ± 5.61
S-190B Color	76	62	0-33	22.9 ± 3.13	13-49	37.2 ± 6.08
S-192, 1, 7, 9, Color	68	61	0-38	33.2 ± 8.43	28-52	37.4 ± 4.81

TABLE XV.- VEGETATION ANALOGS MOST LIKELY TO BE CONFUSED IN VISUAL INTERPRETATION OF SPACE IMAGERY

		Ground Truth							
		Sa	J	B	P	W	A	S	X
Photo Interpretation Identification	Sa	XXX	+						
	J	+	XXX	++	+			-	++
	B		-	XXX	++				
	P		-	++	XXX	++	+		+
	W		+			XXX	-		++
	A				+	+	XXX	+	+
	S		-		-		+	XXX	+
	X	+	++	+	-	+	-	-	XXX

Numeric Symbol	Vegetation Type	Alpha Symbol
315	Meadows	W
325.1	Sagebrush	Sa
341.2	Ponderosa/Jeffrey Pine Forest	P
341.1	Pinyon-juniper Woodland	J
341.4	Spruce-fir	S
342.4	Aspen	A
347	Oakbrush/Mountain Chaparral	B
	Other Vegetation Types	X

++ = Most likely
\+ = Moderate likelihood
\- = Some likelihood

TABLE XVI.- EARTH RESOURCE DISCRIMINATING POWER IMAGERY FROM SPACE

Film Type	Number of Image Classes	
	Total Discerned	Easily Discerned
S-190A CIR	50	41
S-190B COLOR	40	29
S-190A Red	36	24
LANDSAT-1 CIR	31	29
LANDSAT-1 Band 5	30	19
S-190A IR	25	19
LANDSAT-1 Band 7	24	21

TABLE XVII.- COMPARATIVE COST FACTORS TO ANALYZE AND MAP FROM SPACE IMAGERY

Image Type	Man-hours Interp./ 2,000 Sq. Km.	Number Delin./ 2,000 Sq. Km.	Man-min./ 100 Delin.	Man-min. 100 Sq. Km.	% Pure Types	Avg. Boundary Score
LANDSAT-1 CIR	2.37	56	255	6.99	50	2.03
S-190A COLOR	2.56	84	182	7.67	35	1.69
S-190A CIR	3.56	86	247	10.67	30	2.08
S-190B COLOR	5.02	99	305	14.48	35	1.65
S-192 COLOR	1.40	43	224	4.18	30	2.23

TABLE XVIII.- ACCURACY OF IDENTIFICATION OF DELINEATIONS IN MAPPING, PRELIMINARY DATA

IMAGE TYPE AND LEGEND LEVEL	PERCENT CORRECT
LANDSAT-1 CIR	
320	50
325.1	33
327.1	58
341	86
341.1	67
341.2	100
S-190B COLOR	
320	71
325.1	57
326.1	54
341	61
341.1	59
341.2	38

TABLE XIX.- EVALUATION OF GROUND RESOLUTION AT TWO SCALES FOR EACH IMAGE TYPE

Relative Score; 1 Best, 5 Poorest

Features Judged	LANDSAT-1, CIR	S-190A, COLOR	S-190A, CIR	S-190B, COLOR
Cortez--Business District	3	1	1	2
Cortez--Residential District	5	1	4	1
Dolores--Townsite	4	2	2	1
Escarpments and linears	2	1	3	1
Average Ground Resolution Score with its standard error	3.50 $\pm$ .91	1.25 $\pm$ .35	2.50 $\pm$ .92	1.25 $\pm$ .35

Relative Score:

1 = ++ Both scales = Very clear or obvious
2 = ++ One scale + other scale
3 = + Both scales = Evident
4 = + One scale - other scale
5 = - Both scales = Not evident

TABLE XX.- EVALUATION OF RELIEF DETECTION BY STEREO AT TWO SCALES FOR EACH IMAGE TYPE

Relative Score; 1 Best, 5 Poorest

Features Judged	LANDSAT-1, CIR	S-190A, COLOR	S-190A, CIR	S-190B, COLOR
Elevation change of 65'	5	5	5	5
Elevation change down drainage 600'	1	1	1	1
250' escarpment	3	2	4	2
300' escarpment	1	1	1	1
Less than 200' escarpment	3	2	5	1
1,000' escarpment	1	1	1	1
400' hill on top of mesa	1	2	1	2
600' hill on top of mesa	3	4	4	2
850' ridge and valley	1	1	3	1
200'/mile valley floor	5	4	3	3
225'/mile dip slope	1	2	2	1

Relative Score:

1 = ++ Both scales = Very clear or obvious
2 = ++ One scale + other scale
3 = + Both scales = Evident
4 = + One scale - other scale
5 = - Both scales = Not evident

TABLE XX.- (CONTINUED)

Relative Score; 1 Best, 5 Poorest

Features Judged	LANDSAT-1, CIR	S-190A, COLOR	S-190A, CIR	S-190B, COLOR
200'/mile toe slope	2	1	2	1
170'/mile bajada	4	3	4	3
Elevation difference, high peaks, 8,400' to 9,300'	1	2	2	1
Slope break 2950'/mi.-750'/mi.	2	1	4	3
Slope break 750'/mi.-350'/mi.	2	3	2	1
Average Relief Detection Score with its standard error	2.25 $\pm$ .36	2.19 $\pm$ .32	2.75 $\pm$ .36	1.81 $\pm$ .29

Relative Score:

1 = ++ Both scales = Very clear or obvious

2 = ++ One scale + other scale

3 = + Both scales = Evident

4 = + One scale - other scale

5 = - Both scales = Not evident

TABLE XXI.- CHANGE IN MONOCULAR DELINEATION AND IDENTIFICATION BY STEREO EXAMINATION AT 1:250,000 SCALE IN A 1761 SQ. KM. AREA

Image Type	Line Change		Identification Changes	
	cm.	Ratio of Delin. Den.	Landform	Veget. Ident.
LANDSAT-1	9.3	0.1660	15	12
S-190A CIR	6.5	0.0756	2	6
S-190A COLOR	9.1	0.1083	12	9
S-190B COLOR	6.0	0.0606	30	16

TABLE XXII.- PERCENTAGE CHANGES (IMPROVED CONFIDENCE OF DECISION) BY STEREO INTERPRETATION OF SPACE IMAGERY (ALL TYPES CONSIDERED)

Ground Cover Analog Class		Land Surface Class	
Item	% Changed	Item	% Changed
130, Rockland	11.6	1.2 Flat, riparian bottom-lands	1.9
310, Herbland	14.0	2.2 Undul./Rolling, bottom-lands	1.9
320, Shrub/Scrub	4.6	2.3 Undul./Rolling, planar surfaces	43.3
325, Shrub Steppe	7.0	2.4 Rolling, slope systems	5.7
327, Macrophyl. Shrub	25.6	3.3 Hilly, planar surfaces	3.8
341, Conifer Forest	24.9	3.4 Hilly, slope systems	17.0
342, Hardwood Forest	7.0	4.4 Mountainous, slope systems	26.4
510, Agric. Cropland	2.3		
	100.0		100.0

Figure 1.- Location of the two interregional test areas used in this study: Sierra-Lahontan and Colorado Plateau. (Also noted are two test areas used for a rice study performed as part of this investigation but not reported here: Northern Great Valley and Louisiana Coastal Plain.)

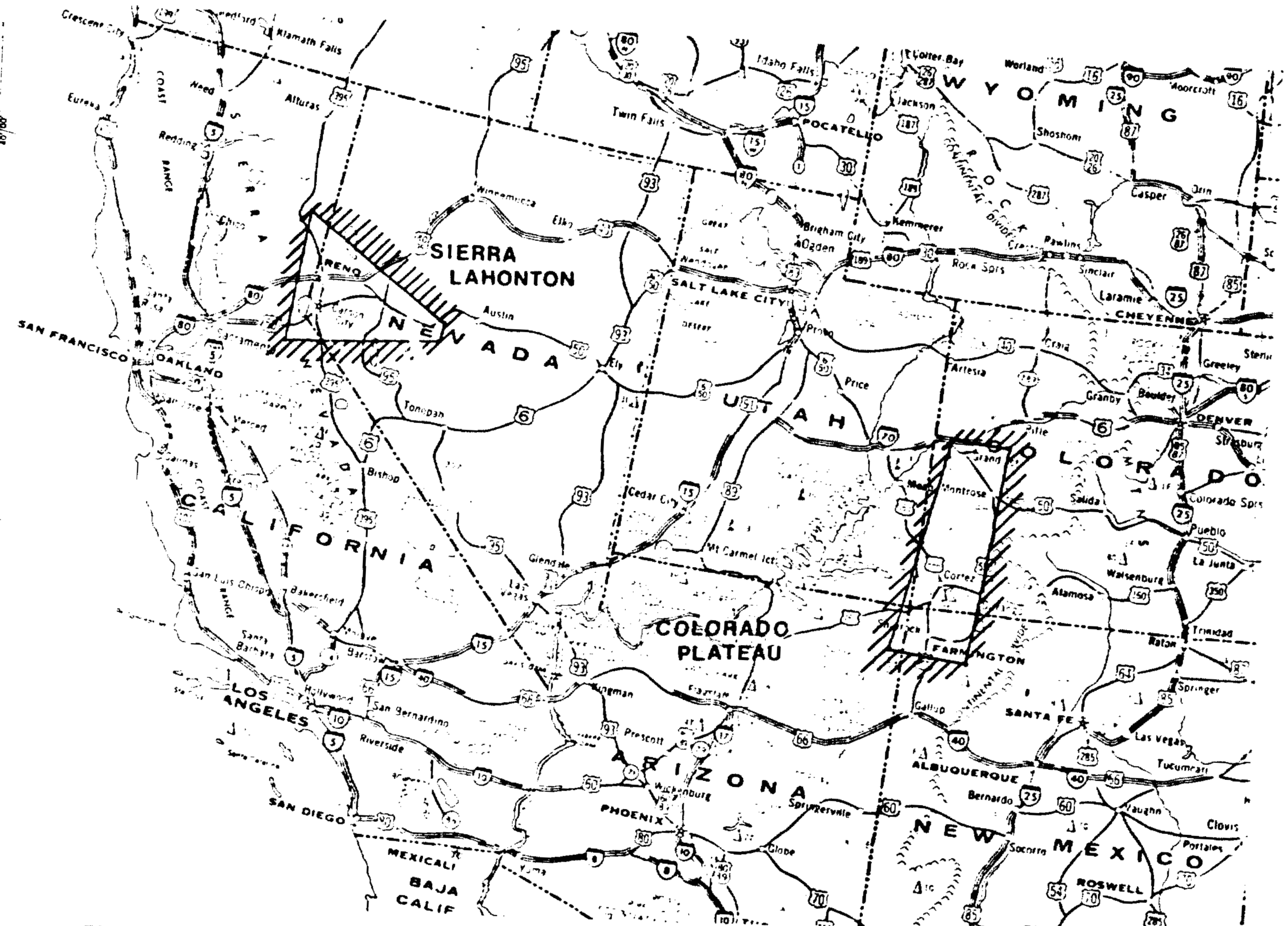
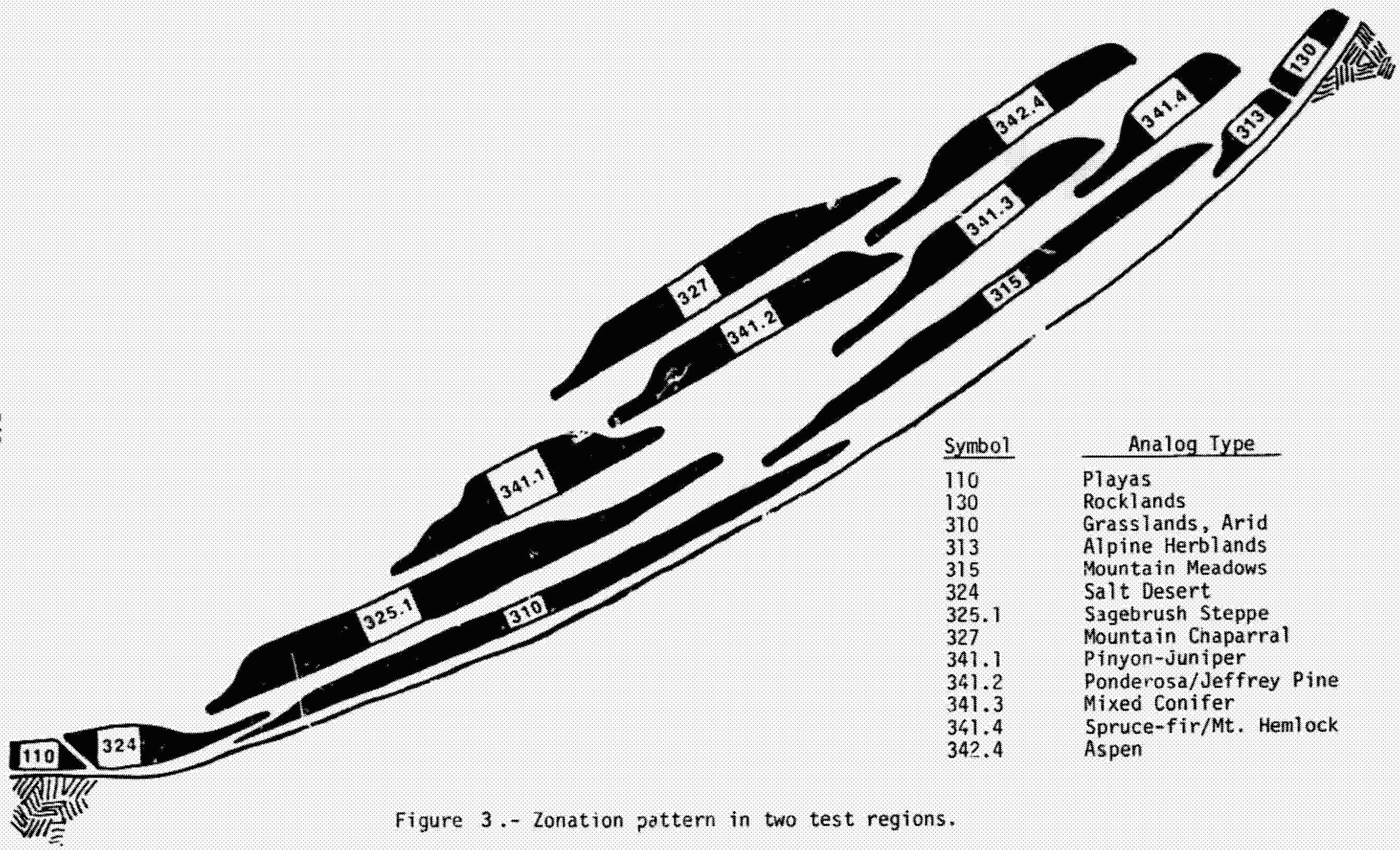


Figure 2.- Approximate boundaries of the two natural vegetation test areas.



Symbol	Analog Type
110	Playas
130	Rocklands
310	Grasslands, Arid
313	Alpine Herblands
315	Mountain Meadows
324	Salt Desert
325.1	Sagebrush Steppe
327	Mountain Chaparral
341.1	Pinyon-Juniper
341.2	Ponderosa/Jeffrey Pine
341.3	Mixed Conifer
341.4	Spruce-fir/Mt. Hemlock
342.4	Aspen

Figure 3.- Zonation pattern in two test regions.

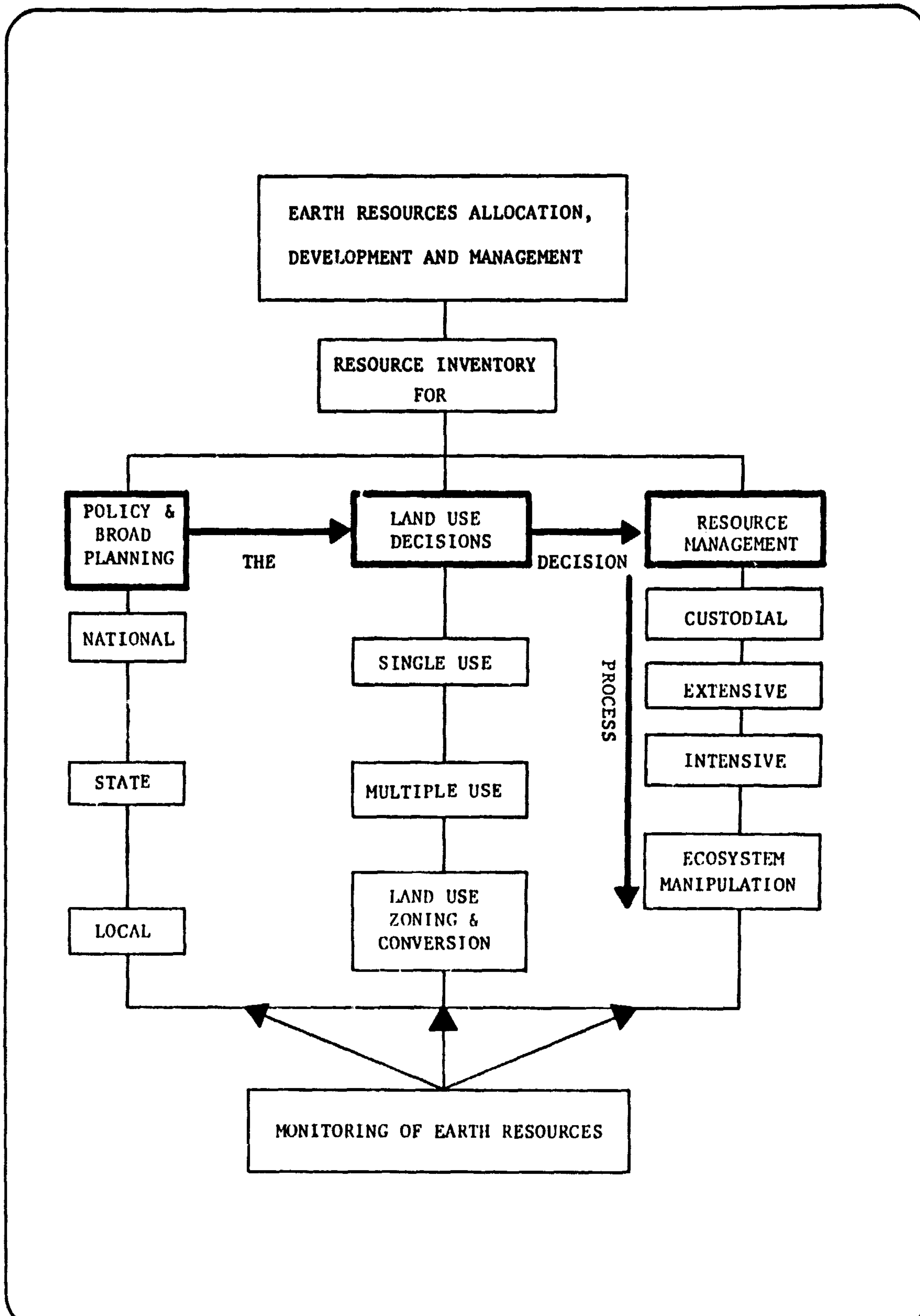


Figure 4.- The decision process in resource allocation and management as it relates to level of problem, scale, and resolution.

Figure 5.- All ground truth observations were located as they were acquired on 1:250,000 scale topographic maps. Support aerial photography missions were also charted on the same maps as indicated by the SW-NE trending black line in this illustration. Locations of key examples of each analog were then transferred to 1:250,000 scale LANDSAT color enlargements for use in interpretation testing experiments. Maps such as these are essential to the accessing of the ground truth record once it has been obtained and filed. The ideal way to match ground truth with the LANDSAT enlargement is by use of a mylar print of the 1:250,000 planimetric and topographic detail.

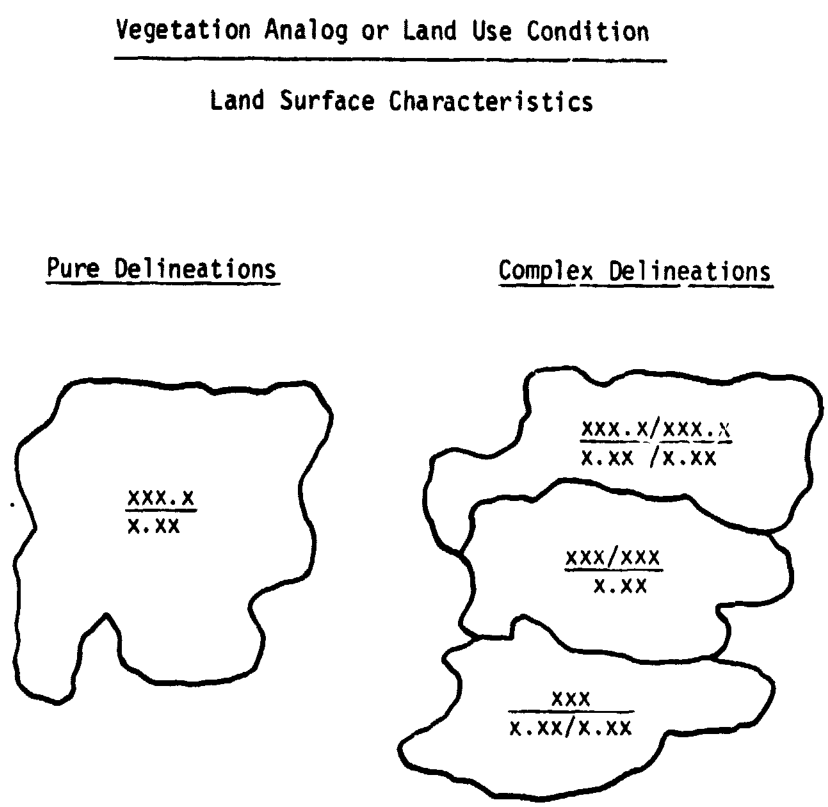
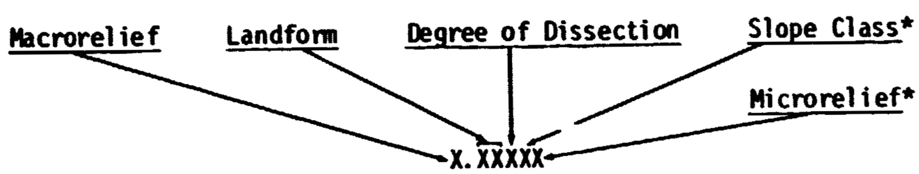
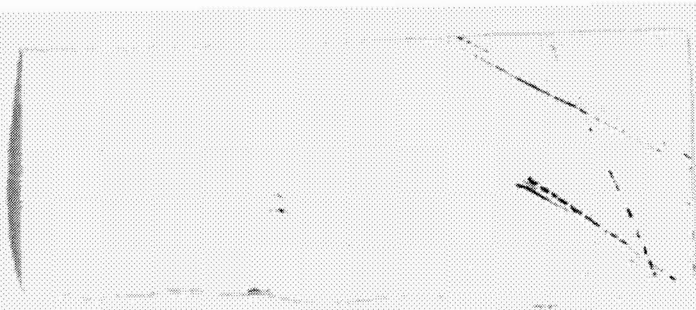


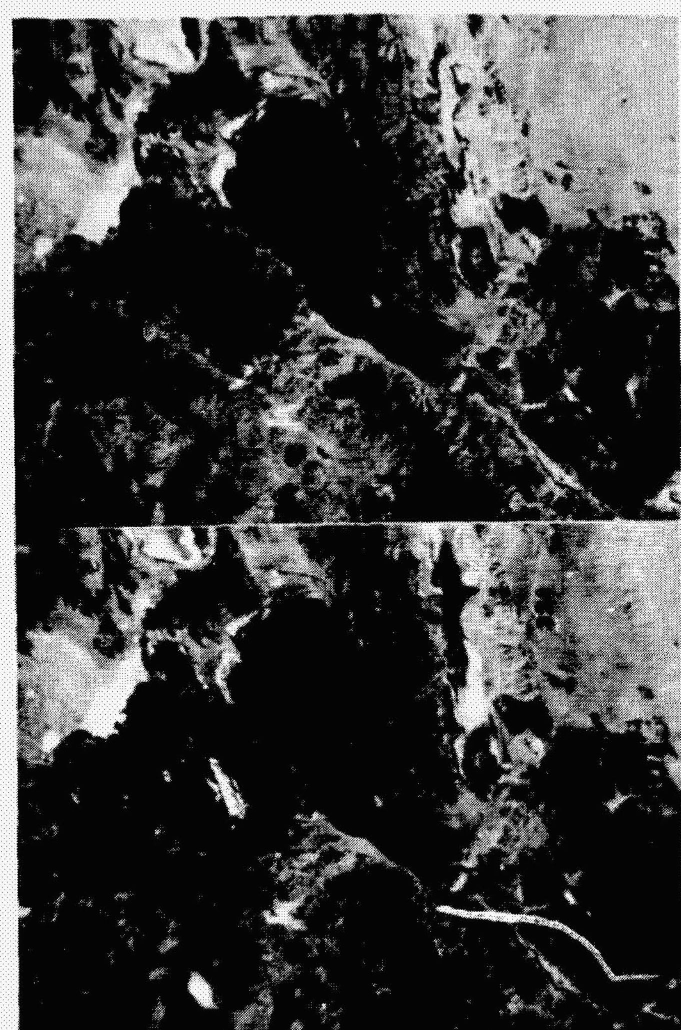
Figure 6.- The symbolic legend format fcr use in delineation identification or in entry into a computerized data base.



*These two levels are generally appropriate to use only with intensive large-scale inventories at scale of about 1:25,000 and larger.

Figure 7.- Symbolic legend format for annotation and description of land surface characteristics.





1002-18125
July 25, 1972

1290-18115
May 9, 1973

Figure 8.- The advantages of multidate imagery for the evaluation of natural vegetation of both range and forest lands must not be discounted. This scene shows how spring vs. late summer imagery can be combined, in the first instance to differentiate lower elevation grasslands (312), sagebrush steppe (325), and even the more productive phases of the salt desert (324). The latter differentiations are very difficult or impossible in late summer imagery. Similarly late spring imagery does not differentiate the mountain brush or chaparral (327), aspen (342), and the mixed pine-oak (343) types but mid- to late-summer imagery (top example) does an excellent job of this discrimination.

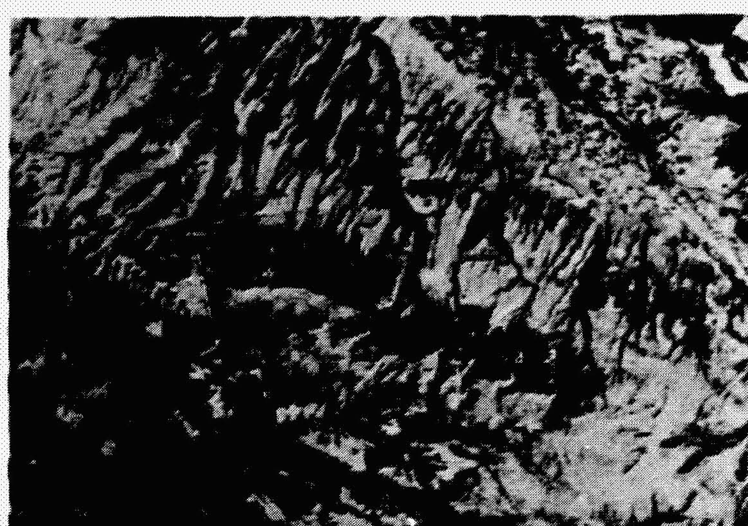


Image ID: 1210-17262
February 18, 1973
LANDSAT-1

Figure 9.- A snow background increases the contrast among many features of importance. The brownish colors in this winter scene of the Uncompahgre Plateau in southwestern Colorado represent coniferous forests and woodlands (341). It is not possible visually to separate the various kinds of these forests except by inference from topographic position. One could reason that most woodlands at the lowest elevations and on south-facing canyon slopes would be juniper woodlands (341.1), that the intermediate forests on the broad plateaus and dip slopes would most likely be ponderosa pine (341.2) and that most of the coniferous forests on protected slopes at middle and upper altitudes would be mixed conifer (341.3) types. Note the sharpness with which the cleared juniper areas (400) southwest of Montrose, Colorado (arrow) are contrasted by the snow cover.

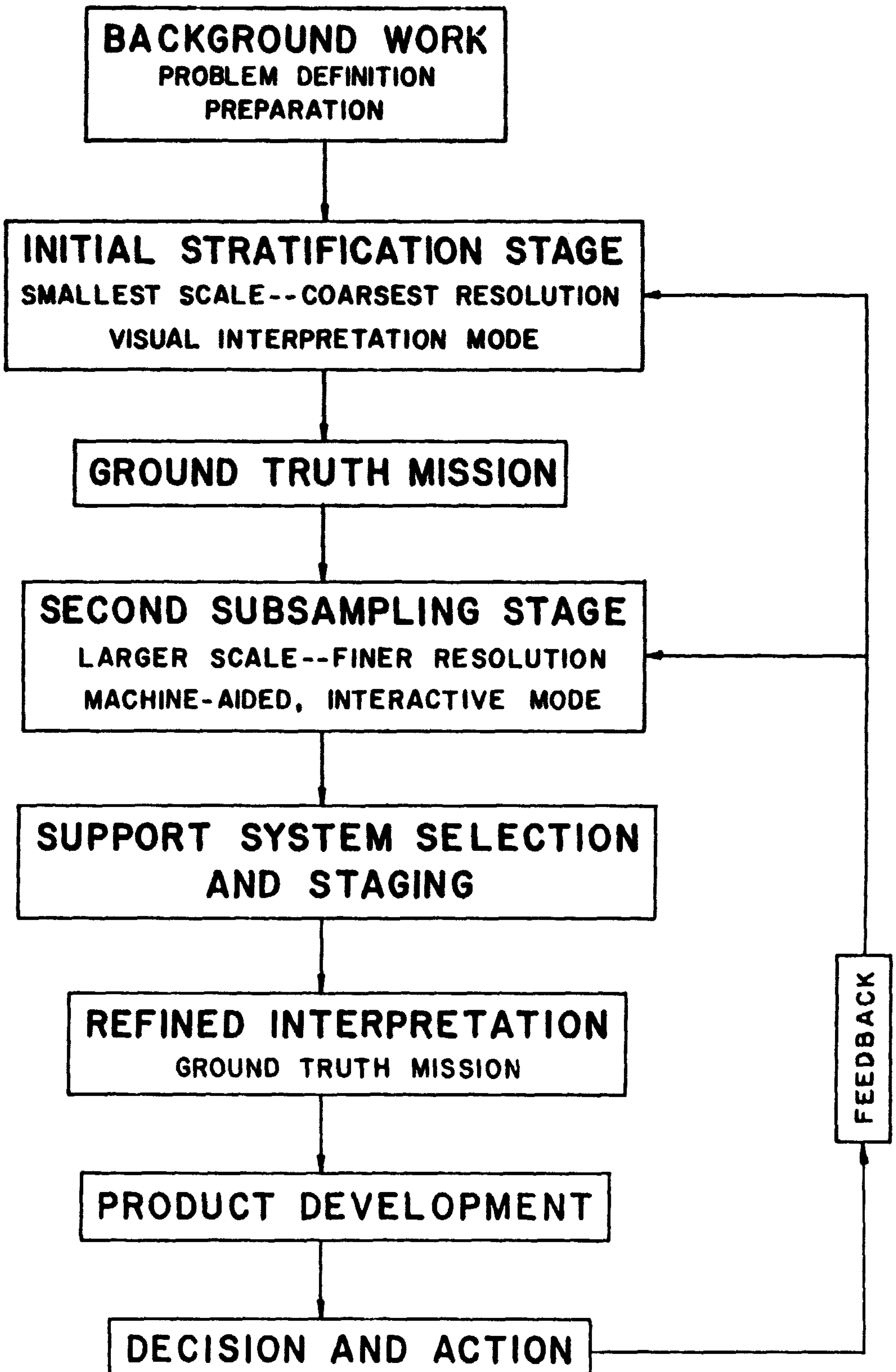


Figure 10.- A generalized flow chart for an operational remote sensing system involving space acquired imagery.

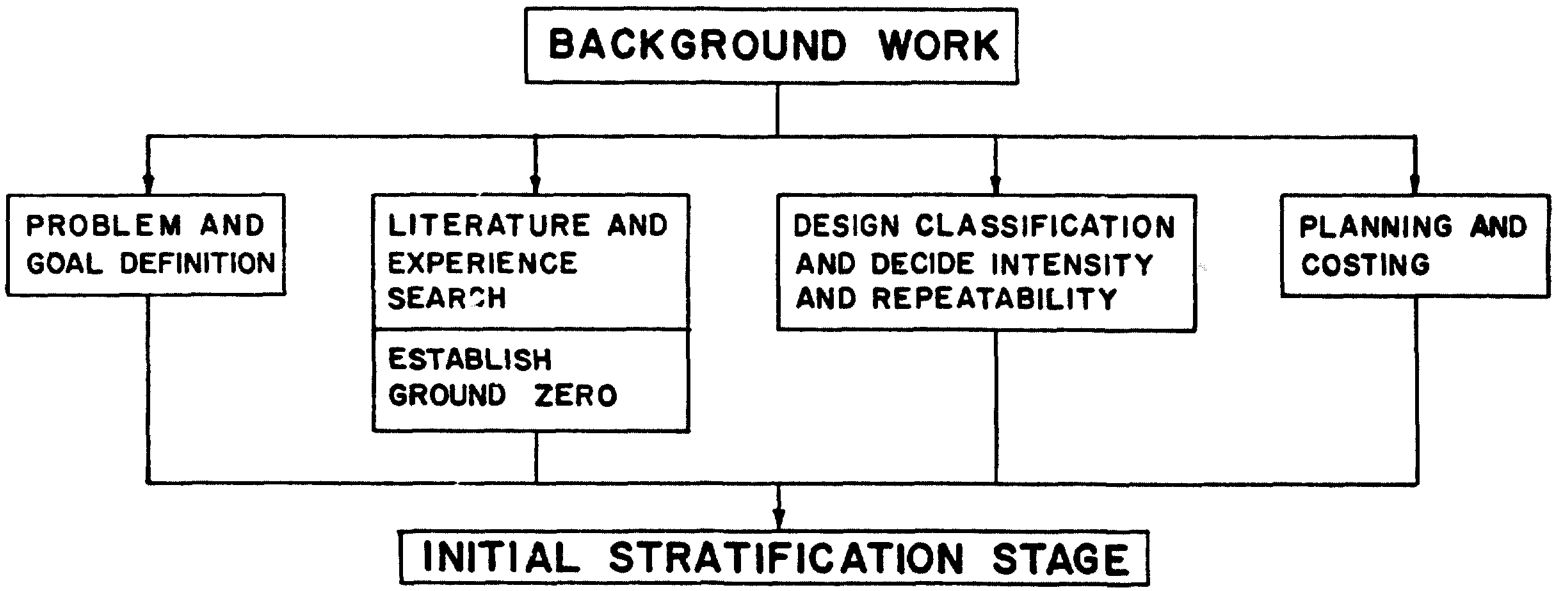


Figure 10a.- Some important details of background to set the stage for effective remote sensing of earth resources subjects.

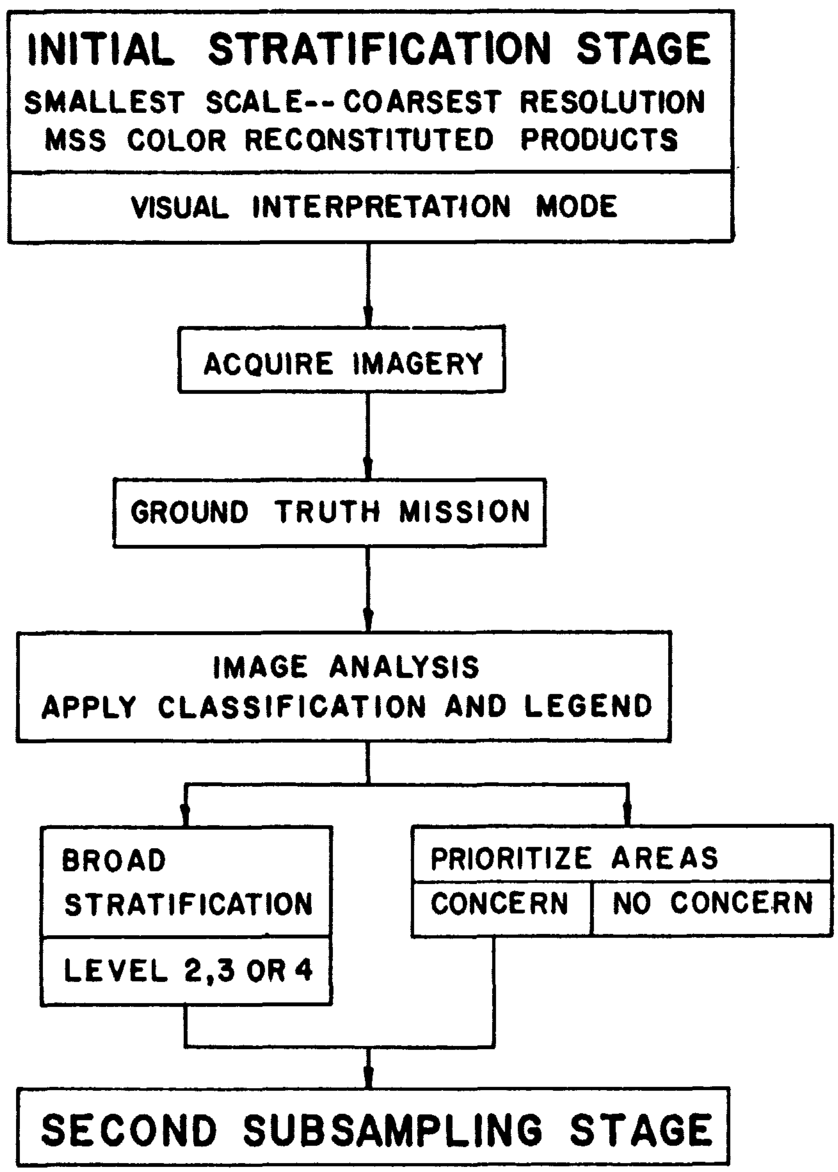


Figure 10b.- The initial stratification and area priority stage of inventory.

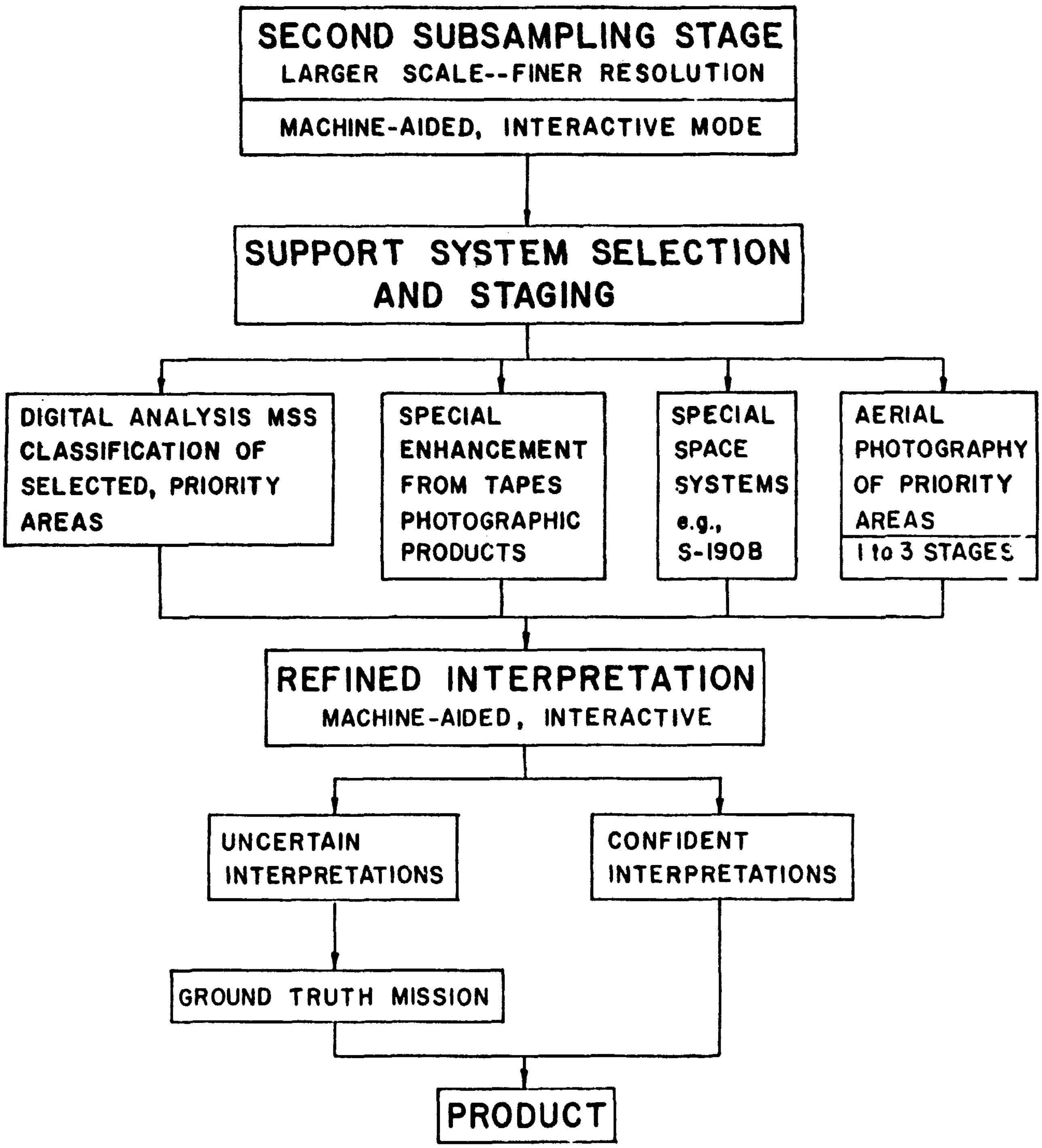


Figure 10c.- The alternative selection and in-depth interpretation stage.

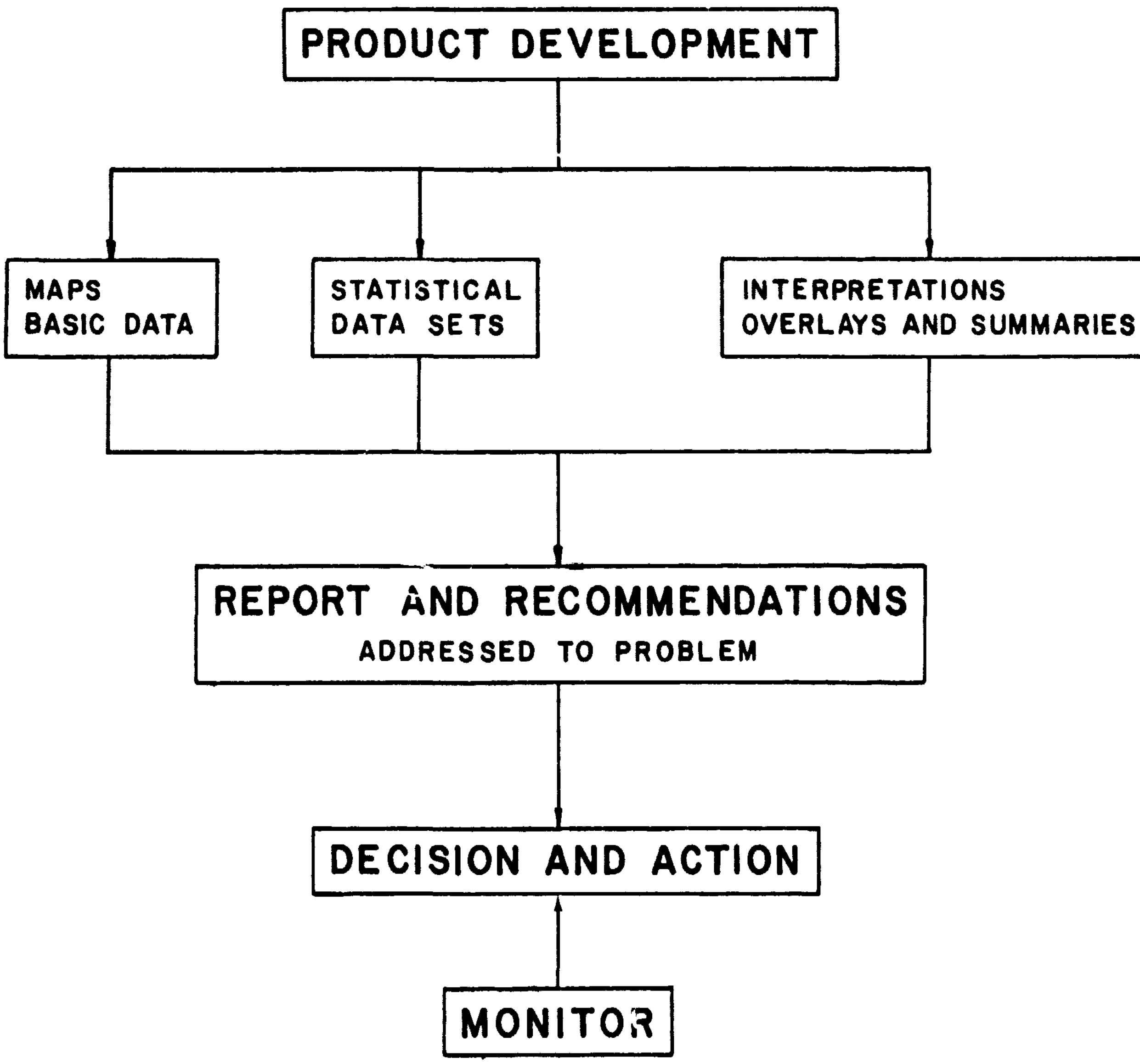


Figure 10d.- The product development presentation and action stages in the use of remote sensing systems.

APPENDIX A

TABLE AI.- Analogs Represented in Test Regions
(+ = well represented with useable examples;
x = poorly represented, marginally
useful examples)

Symbol	Name	Occurrences in Sierra-Lahontan	Occurrences in Colorado Plateau
100-700	All primary classes	+	+
100	Barren Land	+	+
110	Playas	+	x
120	Aeolian barrens	x	+
130	Rocklands	+	+
150	Badlands	x	x
160	Slicks	+	
180	Man-made barrens	x	x
200	Water Resources	+	+
210	Ponds, lakes, and reservoirs	+	+
220	Water courses	x	x
280	Snow/Ice	+	+
300	Natural Vegetation	+	+
310	Herbaceous types	+	+
312	Annual types (mostly *Bromus tectorum* L.)	+	+
313	Forb types (Broad-leaved, herbs dominant)	x	x
314	Steppe, grassland, and prairie	+	x
315	Meadows	+	+
315.1	Sedge and sedge-grass meadows	+	+
320	Shrub/scrub types	+	+
324	Halophytic shrub types	+	+

Table AI (cont'd.)

Symbol	Name	Occurrences in Sierra-Lahontan	Occurrences in Colorado Plateau
324.1	Greasewood types (Sarcobatus vermiculatus (Hook.) Torr.)	+	+
324.2	Saltbush types (A. nuttallii Wats., A. confertifolia (Torr. and Frem.) Wats., A. obovata Mog.)	x	+
324.3	Shadscale/Budsage types (Atriplex confertifolia-Artemisia spinescens Eat.)	+	+
324.4	Bailey's greasewood (S. baileyi Cov.)	+	
324.5	Blackbrush types (Coleogyne ramosissima Torr.)		+
325	Shrub steppe types	+	+
325.1	Sagebrush types (Artemisia spp.)	+	+
325.2	Sagebrush-Bitterbrush types (A. tridentata Nutt.-Purshia tridentata (Pursh) D.C.)	+	x
325.3	Bitterbrush types	x	x
326	Sclerophyllous shrub	+	x
326.1	Manzanita chaparral (Arctostaphylos spp.)	+	x
326.2	Oakbrush chaparral (Sclerophyllous-Evergreen Quercus spp.)	+	
326.3	Snowbrush (Ceanothus velutinus Dougl.)	+	+
326.4	Chamise (Adenostema fasciculata H. & A.)	+	
326.5	Curlleaf Mountain Mahogany (Cercocarpus ledifolius Nutt.)	x	x
327	Macrophyllous shrub	+	+
327.1	Oakbrush chaparral (Q. gambelii Nutt.)	+	
327.2	Mountain brush, Serviceberry-Snowberry-Birch leaf Mountain Mahogany (Amelanchier spp.-Symphoricarpos spp.-Ceanothus montanus)	+	+

Table AI (cont'd.)

Symbol	Name	Occurrences in Sierra-Lahontan	Occurrences in Colorado Plateau
327.3	Willow (Salix spp.)	+	+
330	Savanna-like Types	+	+
336.1	Pinyon (Pinus spp.)-Juniper (Juniperus spp.)-Shrub Savanna	+	+
340	Forest and Woodland Types		
341	Conifer forests	+	+
341.1	Juniper or Pinyon-Juniper (Pinus monophylla Torr. and Frem. or P. edulis Engelm., Juniperus osteosperma (Torr.) Little)	+	+
341.2	Ponderosa or Jeffrey pine forests (Pinus ponderosa Dougl., P. jeffreyi Grev. and Balf.)	+	+
341.3	Mixed conifer forests (Pine-Douglas fir-true fir-Hemlock) (Pinus-Pseudotsuga-Abies-Tsuga)	+	+
341.4	Spruce-fir forests (Picea engelmannii Parry ex Engelm, Abies lasiocarpa)	+	+
341.5	Lodgepole pine forests (Pinus contorta Dougl.)	+	+
342	Broadleaf forests	+	+
342.1	Deciduous oak woodlands (Quercus kelloggii Hewb.)	+	x
342.2	Evergreen oak woodlands	+	-
342.3	Bottomland cottonwood (Populus wizlizenii (Wats.) Sarg.)	+	+
342.4	Aspen types (Populus tremuloides Michx.)	+ x	+
343	Conifer-hardwood forests	+	+
343.1	Aspen-spruce-fir forests	-	+

Table AI (concluded)

Symbol	Name	Occurrences in Sierra-Lahontan	Colorado Plateau
343.2	Pine-oak forests	+	-
414.0	Cleared juniper rangeland, seeded to grass	+	+
425.1	Cleared juniper rangeland, sagebrush understory	+	+
500	Agricultural cropland	+	+
600	Urban and industrial lands	+	+
700	Extractive industry	x	x

APPENDIX A

TABLE AII.- MAPPING CLASSES AND FORMAT FOR THE ANNOTATION AND DESCRIPTION OF LAND SURFACE CHARACTERISTICS

Macrorelief   Landform   Degree of Dissection   Slope Class*

Microrelief*

X.XXXXX

MACRORELIEF:

1. = Flatlands

2. = Undulating to rolling lands

3. = Hilly lands

4. = Mountainous lands

LANDFORMS:

.10 = Depressional, non-riparian

.11 = Basins (interior drainage, usually with playas or lakes)

.12 = Basins, calderas

.13 = Peneplanes

.20 = Bottomlands, riparian

.21 = Stringer or narrow river and stream bottomlands and limited terraces

.22 = Wide river bottomlands with floodplain and terraces

.23 = Depressional drainage ways

.24 = Desert wash

*These two levels are generally appropriate to use only with intensive large-scale inventories at scale of about 1:25,000 and larger.

Table AII (cont'd.)

.30 = Planar surfaces (upland, above classes X.1 and X.2)

.31 = Valley fill (down slope erosional)

.32 = Fans and bajadas

.33 = Lake or marine terraces

.34 = Pediments

.35 = Flat to strongly undulating plateaus, mesas, benches, and broad ridgetops

.36 = Flat to strongly undulating dip slopes

.XX1 = Smooth, undissected

.XX2 = Moderately dissected

.XX3 = Strongly dissected - secondary erosional cycle

.40 = Slope Systems (vegetation and soils tend to change with slope)

.41 = Escarpments

.42 = Valley or canyon slope systems (the valley floor falls in X.3 class). Tertiary levels based on drainage pattern.

.43 = Strongly undulating to rolling uplands

.44 = Butte and isolated hill slope systems

.45 = Hill and mountain, more or less angular slope systems. Tertiary levels based on drainage pattern.

.000X* = Exposed (1), or protected (2)

MICRORELIEF:*

.XXXX1 = Convex

.XXXX2 = Concave

.XXXX3 = Ridge and swale

.XXXX4 = Mounded

.XXXX5 = Pitted/slumped

.XXXX6 = Patterned ground

.XXXX7 = Badlands

SLOPE CLASSES:*

Slope Range %	Slope Class Digit
Simple Slope Systems	
0 - 5	.XXX1
5+ - 15	.XXX2
15+ - 30	.XXX3
30+ - 50	.XXX4
50+ -100	.XXX5
100	.XXX6
Complex Slope Systems	
0 - 30	.XXX7
0 - 50	.XXX8
30 -100+	.XXX9

*Generally used only on intensive inventories done at scales of 1:25,000 and larger.

APPENDIX B1 - GUIDELINES FOR DELINEATION AND IDENTIFICATION IN MAPPING EXPERIMENTS

DELINEATION GUIDELINES

The imagery will be delineated by considering vegetation, land uses that have changed the earth surface feature, barren land, water resources, macrorelief and landform. A specific numerical legend is provided for each of these categories. Study the legend classes before you start actual delineation to become familiar with the criteria for delineation.

When you are ready to begin delineation, fill out the top of the record form, paying particular attention to the time of starting, time of ending, and a best estimate of lost time through interruption during the working period. Try to do the work in a period when you can eliminate interruption.

Pure Delineations

1. Map pure delineations whenever possible. Map pure delineations first and work to harder and harder examples.
2. First delineate the most contrasting subjects and work to the less and less contrasty until a further subdivision of the landscape is no longer practical and meaningful.
3. Map strongly contrasting, highly important features (such as highly productive types and urban or agricultural areas) to a minimum area of 1/2 sq. cm. *
4. Map contrasting, moderately important features to a minimum of 1 sq. cm. *
5. Allow inclusions (i.e., small areas that do not match their homogeneous surroundings) that are ignored in symbolization up to an aggregate of 10% of the delineation area as long as they do not fit condition 2 or 3. Avoid "lumping" for reasons shown in the accompanying example. Figure 1.
6. If the macrorelief-landform changes but the vegetation does not, make separate delineations with a common numerator, and vice versa.

Complexes

1. Delineate the obvious and simplest complexes first, work toward hardest.
2. When mapping complexes, never map more than 3 characteristics or earth surface features in the same delineation--strive generally for two, and remember that

* The "minimum area" specified represents the smallest area as seen on the imagery, which, if found to exhibit a unique appearance, will be separately delineated. Many delineated areas, however, will be much larger than the minimum because they are essentially homogeneous despite their large size.

Appendix B1 (cont'd.)

a significant change in the proportion of any <u>one</u> characteristic or earth surface feature can necessitate separate delineation of the area in which it is found, provided that it exceeds the "minimum area" standard.

3. Inclusions aggregating less than 10% of the area should be ignored.

IDENTIFICATION GUIDELINES

1. Enter identification symbol(s) by number.

   a. Push identification as far toward refined classes as you can, to the point that you consider the odds favor the probability of a right decision, i.e., >50 percent.

   b. If you can't make an identification or distinction at one hierarchical level, back up to the most refined level that does permit you to meet condition 1.a.

2. Do not symbolize inclusions.

3. In identification of complexes, enter symbols of components or features in decreasing order of areal extent within the delineation.

4. Symbolize both numerator and denominator as follows:

$$\frac{\text{SURFACE FEATURE}}{\text{LANDFORM}}$$

APPENDIX B2.- MAPPING EXPERIMENT, NATURAL VEGETATION

Name of P.I.:____________________

Date:____________________

TIME START:__________ TIME FINISH:__________ LOST TIME:__________

Delin. No.	In Image Quad.	Boundary Rating	Ident. Rating	IDENTIFICATION						Propor- tion of Area
				Symbol	%*	Symbol	%	Symbol	%	

*If pure type leave blank; if complex enter in 10% classes 2, 3,...8 (remember a 10% class is ignored as an inclusion).

REMOTE SENSING APPLICATIONS IN KANSAS

B.G. Barr, Jerry C. Coiner, and Donald L. Williams
The University of Kansas Space Technology Center
University of Kansas, Lawrence, Kansas 66045

ABSTRACT

The Satellite Applications Laboratory of the University of Kansas Space Technology Center has since April 1972 carried out a program designed to assist decision makers in local, state and regional agencies in the application of remote sensing techniques to their activities. To date twenty projects have been initiated in support of twenty-nine separate municipal, county, regional, and state agencies or entities. Several data products have been prepared for the use of these agencies based on LANDSAT imagery; high altitude color, color infrared, and multispectral black and white photography; and imagery from a Hasselblad camera cluster flown in the University's aircraft.

Projects are organized in six sequential phases designed to demonstrate the utility of remote sensing in the context of the user agency. After reviewing these phases, four projects are detailed to illustrate the methods and results of applications projects. Two of these projects have resulted in single user decisions during the past year related to: (1) completion of an interstate highway and cancellation of construction plans for a large reservoir, and (2) zoning changes around a smaller reservoir. Two on-going projects are also discussed: (1) a multi-user project related to the expansion of irrigation in Kansas, and (2) a program of activities leading to incorporation of remote sensing into the data acquisition methods of Kansas City, Kansas.

INTRODUCTION

Officials at all levels of government are daily faced with requirements for objective data to be employed in the decision-making process. At lower levels of government, acquisition of data by traditional methods is often beyond the physical and economic resources of the governing body. Consequently, decisions are frequently based upon incomplete or potentially biased data sets.

Since 1972, the staff of the University of Kansas Satellite Applications Laboratory has, with the assistance of the NASA Office of University Affairs, engaged in a program of activities designed to acquaint state and local officials of Kansas and neighboring states with the potential of remote sensing as an alternative data collection system. This review outlines the procedures employed in acquainting officials with the potential of employing remote sensing data within their own context and summarizes results obtained in four projects with which the Applications Laboratory has been associated. These projects have been designed both to answer specific questions of officials and to provide a basis for communication by demonstration.

Organization of a Project

Six phases of application activity may be identified in projects undertaken by the Applications Laboratory (Figure 1). The Contact Phase is intended to establish rapport between experts in the use of remote sensing technology and the government official in need of data. Activities in this phase have taken the form of two Kansas Governor's Conferences on Remote Sensing, short courses on the interpretation of LANDSAT and high- and low-altitude aircraft imagery for state and local government officials, articles in such magazines as the Kansas Government Journal (ref. 1) and the Kansas Water News (ref. 2), and individual contact between government officials and Laboratory personnel trained in specialties paralleling those of the government official, i.e. urban and regional planning or natural resources.

This Contact Phase may lead to agency personnel and/or Laboratory staff identifying a data requirement which can be solely or partially met from imagery sources. At this point an attempt is made to specify a project and the agency/Laboratory relationship is extended to the Project Definition Phase. During this phase questions about the scope of the project, the intended use of data interpreted from the imagery, and how costs will be shared are answered. Upon mutually satisfactory assessment of the project,

a task group is organized among personnel within the Laboratory. This task group may include agency personnel working in the University's Space Technology Center and/or Laboratory personnel working within the agency.

Actual utilization of remotely sensed data begins with the Project Initiation Phase. During this period critical operations are conducted which may be focal to the success or failure of agency use of remotely sensed data. These include sensor selection and mission planning. After sensor selection, image acquisition is undertaken from existing sources (EROS data center, NASA Houston, etc.) if the imagery is not already available in the Laboratory's film library. Alternatively, imagery may be acquired by the University's aircraft or by a private contractor. Parallel to image acquisition is interpretation development. This activity relies on the experience of the Laboratory's image interpreters and literature review to determine if the interpretation has been undertaken before. If it has, the methods and accuracy of the effort are elicited from the literature. If not, suitable interpretations to successfully accomplish the project are developed and documented.

After imagery has been acquired and effective interpretations developed, the actual interpretation and preparation of final products for use by agency personnel occur during the On-going Project Phase.

When the products required for the project have been developed, they are delivered to the user agency and Laboratory personnel prepare documentation for further reference and to support the agency in using the products in the Project Completion Phase. Efforts are also made to document the use of the remote sensing products in the agency environment.

This leads to the Continuing Support Phase of the application effort, in which support to state and local agencies is provided in the form of personnel training, product improvement, fulfillment of new product requirements, and consultation services in data utilization. The continuing support phase can be seen as the culmination of the Laboratory's effort. Agency/Laboratory projects which reach this phase explicitly indicate agency acceptance and continuing utilization of remotely sensed data.

SELECTED PROJECTS

The following projects illustrate some of the contexts into which remote sensing is finding its way in the governments of Kansas and Missouri. Although the attention of the Laboratory staff has been directed primarily to meeting the needs of Kansas officials, on three occasions officials of Missouri, introduced to the program through the Kansas Governor's Conferences, have requested assistance on specific projects. The projects, from both Kansas and Missouri, described below illustrate both the range of potential application and the ways remote sensing may be used in single-decision and multi-user problems. The first two problems discussed illustrate the single-decision approach and their relationship to the methodology outlined above is transparent. Multi-user, multi-decision problems of the type discussed later are less sharp but, in the long run, potentially more significant in that they represent full acceptance and incorporation of remote sensing into the data collection methodology used by state and local governments.

Pattonsburg Reservoir and Interstate-35

In early 1973 the Governor of Missouri was faced with a decisional situation concerning completion of Interstate-35 and the proposed Pattonsburg Reservoir project in northwest Missouri (Figure 2). Completion of I-35 had important economic consequences for the Kansas City Metropolitan Region, since the highway provides a direct route from Chicago to Kansas City. At that time I-35 was complete except for a fifteen mile segment in the area of the proposed Pattonsburg Reservoir. In addition to the traffic hazard problems created by the detour over a narrow, dangerous two-lane highway, engineers had estimated that construction of a crossing over the proposed reservoir would cost $30 million, while construction of the segment without the crossing would cost $10 million.

The Governor's staff determined that a need existed for additional analysis on the desirability of the reservoir project before committing funds for the completion of the more expensive reservoir bridge crossing for I-35. The Applications Laboratory was requested to provide objective data to support the group conducting the supplementary analysis.

Color infrared and black-and-white aerial photography was acquired to provide a data base for the reservoir site and the proposed dam. Four classes of land use (crops, pasture, forest, and urban) were interpreted for the Governor's committee and compiled into a map of the proposed inundation area. Statistics on acreage of each land type to be inundated above and protected below the dam were provided. These statistics compensated for a deficiency in the original Environmental Impact Statement which, because it had been prepared for the entire Grand River Project, did not separate data for the Pattonsburg Reservoir from that for several other projects on the river (ref. 3). Analysis of these statistics revealed that without the dam, 58,615 ha (144,780 A.) would be available for agricultural production, while with the dam, agricultural land would be reduced to 45,749 ha (113,000 A.). Based on U.S.D.A. data related to crop values and the image analysis, it was estimated that the loss of agricultural production between 1980 and 2020 would average approximately $5 million per year if the dam were constructed.

The analysis and related maps were sent to the Governor's committee on 31 July 1973, approximately 90 days after the initial request. On 27 August 1973, the committee reported to Governor Bond its conclusion that it would be an unwise use of public funds to proceed with the high bridge crossing and the Pattonsburg Reservoir project with the information currently available. The Governor then decided to postpone construction of the high bridge crossing of the Grand River one year and asked the Corps of Engineers to re-study the justification for the Pattonsburg project in collaboration with several state and federal agencies. On 18 August 1974, at the end of the re-study, the Corps of Engineers announced that the reservoir had been cancelled. The following day the Missouri Highway Department announced that work would begin immediately on the design of a low crossing of the Grand River to allow the completion of I-35.

The decision to cancel the proposed Pattonsburg Reservoir project and thus save $20 million in the construction of I-35 rested substantially on an analysis supported by remotely sensed data.

Measuring the Impact of Clinton Reservoir

In contrast to the preceding problem of whether or not to build a reservoir, Clinton Reservoir is being constructed by the U.S. Army Corps of Engineers near Lawrence, Kansas. When completed in 1978, the reservoir is expected to attract heavy recreational use from the two million residents of the Topeka-Kansas City Corridor (Figure 3). Perry Reservoir, the only comparable facility in the area, has been subjected to overuse and uncontrolled development of the adjoining lands. Citizens of the Clinton Reservoir area, which includes the city of Lawrence, Kansas, have demanded an orderly development program for the reservoir site which will preserve the environmental quality of the area.

In response to this demand, in late 1972 the Lawrence-Douglas County Commission placed a moratorium on any zoning changes in the area of the reservoir and directed the Lawrence Planning Department to prepare a comprehensive development plan by July 1973. The plan was required to identify privately owned lands which were best suited for urban development and those lands best suited to remain rural, agricultural or natural. The planning department requested assistance from the Applications Laboratory in the employment of remote sensing to inventory specific characteristics of the area so that planning policy could be based on current unbiased data.

Large-scale multiband aerial photography similar to that acquired at Pattonsburg was used to meet this requirement. Image interpretations included (1) selection of areas of scenic value; (2) mapping of vegetation, including dense and open woods; and (3) mapping of wildlife habitat quality. Interpretations were then converted to legend classes which were established by planning department personnel and indicated the compatibility of each area to urban development or to the desire to preserve current use.

Maps of each of the development factors were combined to produce a development potential map. The potential map (Figure 4) has the following structure: areas with dense woods, high quality wildlife habitat, and scenic areas were most suitable for preservation; areas with open woods, low quality wildlife habitat and scenic areas were most compatible with urban development. Based on these data, the Planning Department recommended a development policy and the Planning Commission made the following policy decisions.

1. Densely wooded areas were to "be treated as a unique resource and retained wherever possible."

2. Areas of high wildlife habitat quality would be preserved while those of low quality would be available for development.

3. Areas of steep slopes would be denied to development.

The first test of this policy came in late 1974 when a local developer requested re-zoning for the Yankee Tank Subdivision. The developer had used the general plan and the Applications Laboratory imagery in preparing his site plan. Because the site plan conformed to the established policies, the Commission re-zoned the area.

In this case remotely sensed imagery was used to provide inputs to one of the most controversial problems in the United States today: land development. A significant aspect of this project, which points out the strength of remotely sensed data, was the use of the same imagery by both the planning commission and the developer in establishing their positions and policies.

Center Pivot Irrigation

The preceding two projects have illustrated the SINGLE DECISION orientation in which many of the program's operational projects have been framed. This next use of remote sensing deals with a much more pervasive and complex issue of interest to many governmental organizations: the rapid increase in irrigation, particularly in the form of center pivots, and its possible long-term consequences.

Center pivot sprinkler irrigation is a recent innovation to agricultural practice in the Great Plains of North America. The system was first employed in southwestern Nebraska in the early 1950's and has since spread throughout North America wherever suitable conditions for this type of irrigation have been found. The circular shape of fields irrigated with center pivots is anomolous on images of Kansas because most fields are rectilinear. Consequently, center pivots are readily distinguishable on aerial photographs and on images produced by LANDSAT (ref. 4).

One area of high suitability for the use of center pivot irrigation is in southwestern Kansas (Figure 5). Since center pivot irrigation was introduced into this region in the early 1960's it has undergone a rapid expansion and by early 1974, 2,223 center pivots had been installed in 12 southwestern Kansas counties, thereby bringing more than 121,000 ha (300,000 A.) into sprinkler-irrigated crop production[1]. This represents approximately 12 percent of all land annually harvested for crops in the region. Expansion has been and continues to be rapid throughout the region primarily because the availability of center pivot systems has made possible the opening of new land to cultivation and has proved extremely productive in terms of crop yields on these newly cultivated lands. The availability of well drillers and sprinkler systems appears to be the only factor limiting installation rates.

Because of the periodic coverage supplied by LANDSAT, it has been possible to monitor the annual increase of center pivots in the region. How growth may be charted is exemplified by the case of one county where 11 center pivots were present in 1965. U.S. Department of Agriculture aerial photographs acquired in 1971 were interpreted to indicate an increase to 252 center pivots by that year. The annual increases for 1972 through 1974 were, respectively, 86, 121, and 131 new installations, giving the total of 590 units in the county in 1974. The pattern of growth illustrated by Figure 6 clearly demonstrates the continued rapid diffusion of the innovation in this region.

The primary impact of the growth of center pivots may be stated with respect to three factors. First, this irrigation system has affected crop production in two ways: (a) by shifting production away from wheat and into feed grains, particularly corn, and (b) by sharply increasing total production of agricultural crops in the region. Second, as is evident on Figure 6, natural vegetation is being removed from substantial areas, particularly in the Sand Hills south of the Arkansas River, because of the effectiveness of center pivots on sandy soils. The new irrigation system has, then, greatly reduced the area of

[1]It should be noted that in early experiments in Finney County it was discovered that very few center pivots were mapped if they were not actually present but that as many as 6 or 7 percent of those present were not detected by interpreters of LANDSAT images (ref. 4). Consequently, the actual number installed may be slightly higher than the number reported here. For example, present information indicates that 200 units are installed in Seward County, although only 185 units were interpreted from the imagery and therefore appear on the map.

native grassland and replaced it by irrigated cropping. Third, the use of groundwater to supply this irrigation system as well as flood irrigation systems already in place is leading to a decline in the availability of groundwater since use exceeds the recharge to the rock formations which yield water in this area (ref. 5).

The 2,223 center pivots presently installed in southwestern Kansas are not uniformly distributed over the region but are concentrated in several areas. Three primary factors operate to determine this distribution. Two of these are physical and one is cultural. The two physical factors are soil type and availability of groundwater while the cultural factor is the alternative type of land use which exists on each parcel of land. The two physical factors are jointly indicated on Figure 5 to suggest the potential of each part of the area for the installation of center pivots. Four major types of soil are indicated on the map: (1) clayey soils on sloping sites, (2) clayey soils on nearly level sites, (3) complex mixtures of clay and sandy soils or loamy soils generally on nearly level sites, and (4) sandy soils. The nature of water application under this sprinkler irrigation system is such that any salts present in the water will be rapidly concentrated in the upper part of the clayey soil profiles. Thus, although some center pivots are installed on relatively clayey soils, their returns are less satisfactory than are those that are placed on very sandy sites. At the same time, flood irrigation cannot be used on very sandy soils because the water soaks into the ground so rapidly that it cannot be applied over the whole length of a normal size field. Therefore, the higher the sand content of the soil, the more suitable the site is for installation of a center pivot system. Center pivots have made it possible to irrigate areas which are not suited to other types of irrigation (ref. 6). In the most extreme cases, they have opened to cultivation lands which were previously not suitable for crop production. For example, in the soil survey report for Finney County, Kansas, published in 1965, it was stated that a large stabilized sand dune area was not suited to any type of cultivation (ref. 7). At present, this area contains large acreages of cultivated land as a result of center pivot irrigation.

Since irrigation water is derived almost entirely from wells in southwestern Kansas, the availability of groundwater supplies is also a limiting factor on the installation of any type of irrigation system. Four classes of water availability are indicated on the map (Figure 5). These classes range from groundwater not generally available to abundant quantities of groundwater. The color scheme used on the map results in the display of the joint consequences of water availability and soil type. Increasing water availability is indicated by the increasing degree of blueness of the map unit. Soil type is indicated by the yellowness of the area. Consequently, those areas which have both sandy soils and abundant groundwater are indicated in dark green, while those areas with neither sandy soils not substantial quantities of groundwater are indicated in very pale green. Other colors develop as a result of various combinations of the two factors. The resulting patterns demonstrate that, while there are substantial areas suited to center pivot irrigation, there are also substantial areas which are unsuited to the system's use. As is readily evident, most center pivots are located in those areas favorable to such installations. The concentration of center pivots, particularly in the central portion of the area, are so located because groundwater is abundantly available and the soils are distinctly sandy. However, there are several other areas which are suitable for this type of system which contain very few center pivots. Often, these areas are already completely occupied by other forms of irrigation or some other intensive type of land use which will not be replaced by center pivots.

In contrast to this great concentration, center pivots are completely absent from the sandy soils in the northwest part of the area. Consideration of the availability or, in this case, non-availability of groundwater makes it readily apparent that although the soils may be suitable, the western sandy area is not suited to irrigation because water is unavailable. In contrast, the area along the northern edge of the map contains very few center pivots because of generally unsuitable soils. Frequently, groundwater is unavailable in the same region.

Using the preceding analysis of growth and diffusion of center pivot irrigation in combination with the total irrigated acreage also interpreted from LANDSAT images, the Applications Laboratory, with the encouragement from legislative leaders, has established a joint program with the Kansas Geological Survey, the state agency primarily responsible for preservation of natural resources. This program envisions the development of a series of recommendations on irrigation based on both existing well records of water table drawdown and areal expansion elements from LANDSAT to provide the state regulatory agencies with the information necessary to decide how the limited water resource should be used for the maximum social benefit with minimum environmental disruption. Results of this investigation are also of value to the Kansas Forestry, Fish & Game Commission in analyses of prairie chicken habitat destruction and the Kansas Department of Economic Development and regional planning commissions in planning for future population and land use changes in Kansas.

Remote Sensing in the Urban Milieu

In addition to analyses in rural areas, the Applications Laboratory has been supporting urban governing and planning bodies. The increased application of remote sensing data in this context, as illustrated by the case of Kansas City, Kansas, is encouraging.

Kansas City, Kansas, is a city of 180,000 located at the confluence of the Missouri and Kansas Rivers (Figure 7). The city is part of the Kansas City Standard Metropolitan Statistical Area (SMSA) of approximately 1,250,000 (1970 census).

In recent years, Kansas City, Kansas, has suffered the ill effects of urban decay noted in many U.S. cities and the city government has faced demands for improved services throughout a growing urbanized area. These conditions have in turn increased the pressure on the governmental agencies for data to support the decision making process. In the main, responsibility for the acquisition of data about conditions in the city has fallen to the Department of Planning and Development. The growing requirement for specific social and economic indicators about the city and the increased cost for acquiring a unit of data caused the city planner to initiate a search for alternative methods of data gathering to allow proper assessment of infrastructure as a surrogate for more abstract social indicators.

The Department of Planning and Development first came into contact with remote sensing techniques through conferences held at the University of Kansas Space Technology Center. However, the utility of the techniques was driven home by events which occurred during the Kansas and Missouri River flooding of October 1973. Image interpreters of the Applications Laboratory provided data on a rapid response basis to support the Kansas City, Kansas/Wyandotte County Civil Defense efforts by identifying weakened areas of dikes, points where dikes were breached, debris jammed into bridges, and assessing flood damage (Figure 8).

Based on this experience, the Department recognized that remote sensing could provide timely, accurate data not available from other sources. They then requested the Applications Laboratory to aid in an assessment of remote sensing data collection for the city government. Initially the program provided examples of high resolution color and color infrared, medium resolution color and color infrared flown by the NASA high altitude aircraft, and LANDSAT-1/2 data over the city. The Department first concentrated on two projects: (1) assessment of dwelling unit conditions in an urban renewal area, and (2) development of simple techniques to acquire data for environmental impact statements. Both of these projects were accomplished with the aid of Applications Laboratory personnel. The number of dwelling units were counted from the photographs. The photo counts indicated substantially more dwelling units in the affected area than had been expected from 1970 census data. The environmental impact data interpreted from 70 mm imagery provided the city with social, economic and physical environment data in a 5 km^2 (2 mi^2) corridor for a total cost of less than $500.00, including data interpretation.

Based on the positive outcomes of the three initial actions that had encompassed the use of remote sensing, the Department of Planning and Development made the decision to use remote sensing as an integral part of their data acquisition effort and a full time image analyst was employed by the planning staff. Since then, the Department of Planning and Development, in consultation with Applications Laboratory personnel, has initiated three major projects of their own.

Data to support the various administrative departments of the city government are maintained in a series of computer files, known generally as an urban information system. These base files contain a map of the urbanized area constructed from the transportation network. The geographic base file project, which was initiated in 1972, had by 1974 reached the level of sophistication where land use data concerning every parcel of land in Kansas City/Wyandotte County could be stored in the file. To determine if this project was feasible the city hired six college students over the 1974 Christmas holidays. After training by Applications Laboratory personnel and using high resolution aerial photography and collateral sources, these employees interpreted and encoded the land use of every parcel of land in a 16 km^2 (10 mi^2) area of the inner city.

In late 1974 the U.S. Congress passed the Community Development Act to replace the existing Urban Renewal Program. The Department of Planning and Development was made responsible for administering the program within the city. They were also told by federal authorities and the City Commission that objective assessment of the program's effectiveness would be required on a periodic basis to determine the level of future funding. With the assistance of the Applications Laboratory, a neighborhood

monitoring program was proposed and accepted as a method of measuring the impact of Community Development funds. The entire city has been flown to acquire natural color photography. This photography is being interpreted to determine the states of twelve variables about each block face in the neighborhood. These variables include status of house roof, street, sidewalks, yards, etc. After the states of these variables are determined they will be combined with variables from the 1970 census and local group inputs to present the City Commission with a program for assigning the Community Development funds. Within twelve months the city will again acquire aerial photographic data for neighborhoods. These new data will be analyzed and comparison with the spring data will establish the degree to which social infrastructure change has occurred in both funded and unfunded neighborhoods, thus allowing the establishment of new priorities and the evaluation of existing projects.

The third project concerns solid waste which had, in the past, been collected by a single company for the entire Kansas City, Kansas/Wyandotte County area. However, when the 1975 bids were opened the costs were over that estimated by the city. This caused the city's finance commissioner to consider alternatives to the present single contract system. He decided to divide the city into five contract zones and let each contract separately, hoping to attract more bidders, especially the smaller minority businesses that the large size of single, city-wide contract, had excluded.

To establish the zones so that they represented equal tonnage of waste in each zone, and to design collection routes that would most efficiently utilize fuel, a network allocation technique was used. Because parts of the county are rural, 1970 census data were too coarse to allow allocation by use of the census data alone. The city then asked the Applications Laboratory interpreters to count dwelling structures from the 1969 census city high altitude flight for the two rural census tracts. When these data were encoded and loaded to the existing geographic base, the allocation process allowed the city to define collection zones and provide bidders with accurate estimates of numbers of dwelling units in each collection zone, thus reducing the risks to the bidders.

The Department of Planning and Development of Kansas City, Kansas, with the assistance of the Applications Laboratory, has completed the conversion from total acquisition of data by contact methods to the acquisition and use of data from remote sensors. At the present time this data is principally provided by low altitude aerial photography. However, as interpretation sophistication of the departmental staff increases, more and more emphasis is being shifted toward the use of high altitude and satellite data.

CONCLUSION

In reviewing the projects discussed above and other projects completed or in progress at the Applications Laboratory, it is evident that remote sensing can serve as an effective new or supplementary data source for state and local government officials. As with the introduction of any new technology, a measure of resistance is encountered in convincing officials to adopt remote sensing. Rapidly rising costs of alternative data collection systems, however, are stimulating many officials to examine the technology and as additional successful demonstrations are completed, routine use of remote data acquisition as an integral part of the data collection methodology is becoming increasingly attractive to those concerned with the environmental problems of Kansas.

ACKNOWLEDGMENTS

Investigations reported in this paper have been supported by NASA Office of University Affairs Grant No. NGL 17-004-024 and several of the cooperating state and local agencies. The discussion of the Pattonsburg Reservoir project was prepared in cooperation with and approved by Mr. Marvin Nodiff, Director - Missouri Department of Natural Resources, Division of Program and Policy Development. The report on Clinton Reservoir was prepared in cooperation with Ms. Martha Munczek, Planner, Lawrence/Douglas County, Kansas, Planning Commission. The report on center pivot irrigation was reviewed by Mr. John Halepaska, Research Associate, Kansas Geological Survey. Mr. Tom Palmerlee, Director of Research, Kansas City, Kansas Department of Planning and Development, and Mr. Ron Domsch, Systems Analyst, Wyandotte County, Kansas, Base Mapping Program, assisted in preparing the description of the urban remote sensing project.

REFERENCES

1. Barr, B.G., and D.L. Williams, 1974, Application of remote sensing in Kansas, Kansas Government Journal, 61: 192-195.

2. ________________ and J. C. Coiner, Remote sensing applications in Kansas, Kansas Water News, (in press).

3. U.S. Dept. of the Army, Office of the Chief of Engineers, 1973, Final environmental impact statement for Pattonsburg Lake, Grand River Basin, Missouri.

4. Williams, D.L., and B. Barker, 1972, Center pivot irrigation in Finney County, Kansas: An ERTS-1 interpretation procedure, Lawrence, Kansas: University of Kansas, CRINC Technical Report 2264-1, 12 pp.

5. Broeker, M.E., and J.M. McNellis, 1973, Groundwater levels in observation wells in Kansas, 1966-70, Kansas Geological Survey Groundwater Release No. 3, 373 pp.

6. U.S.D.I. Bureau of Reclamation, 1971, Kansas water plan studies: Statewide land classification.

7. U.S.D.A., S.C.S. 1965, Soil survey of Finney County, Kansas, Washington: Government Printing Office.

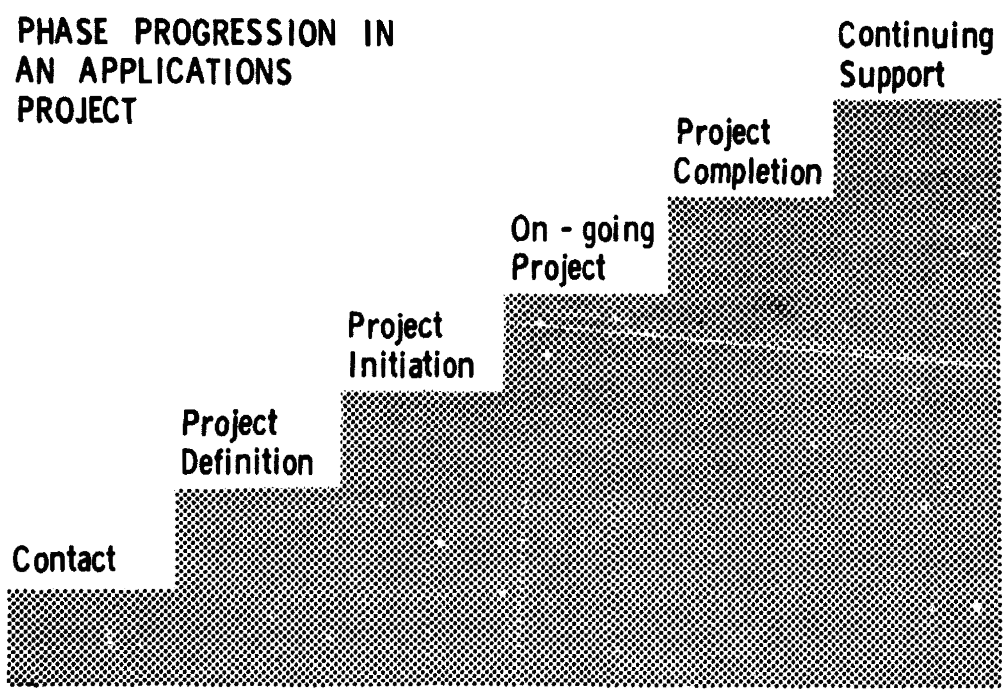


Figure 1. Phase progression in an applications project. The KU Satellite Applications Laboratory may have several projects in various phases at any single time.

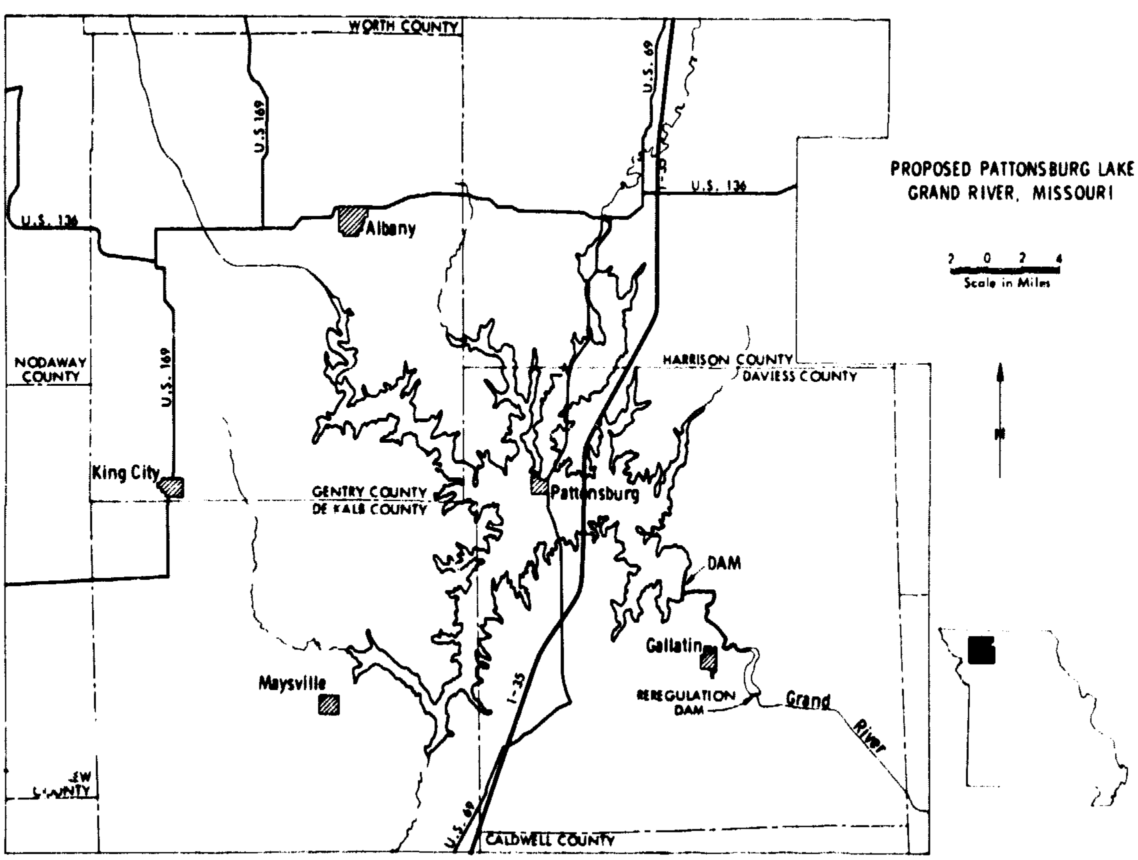


Figure 2. Site of proposed Pattonsburg Reservoir, northeastern Missouri, and the route of Interstate 35.

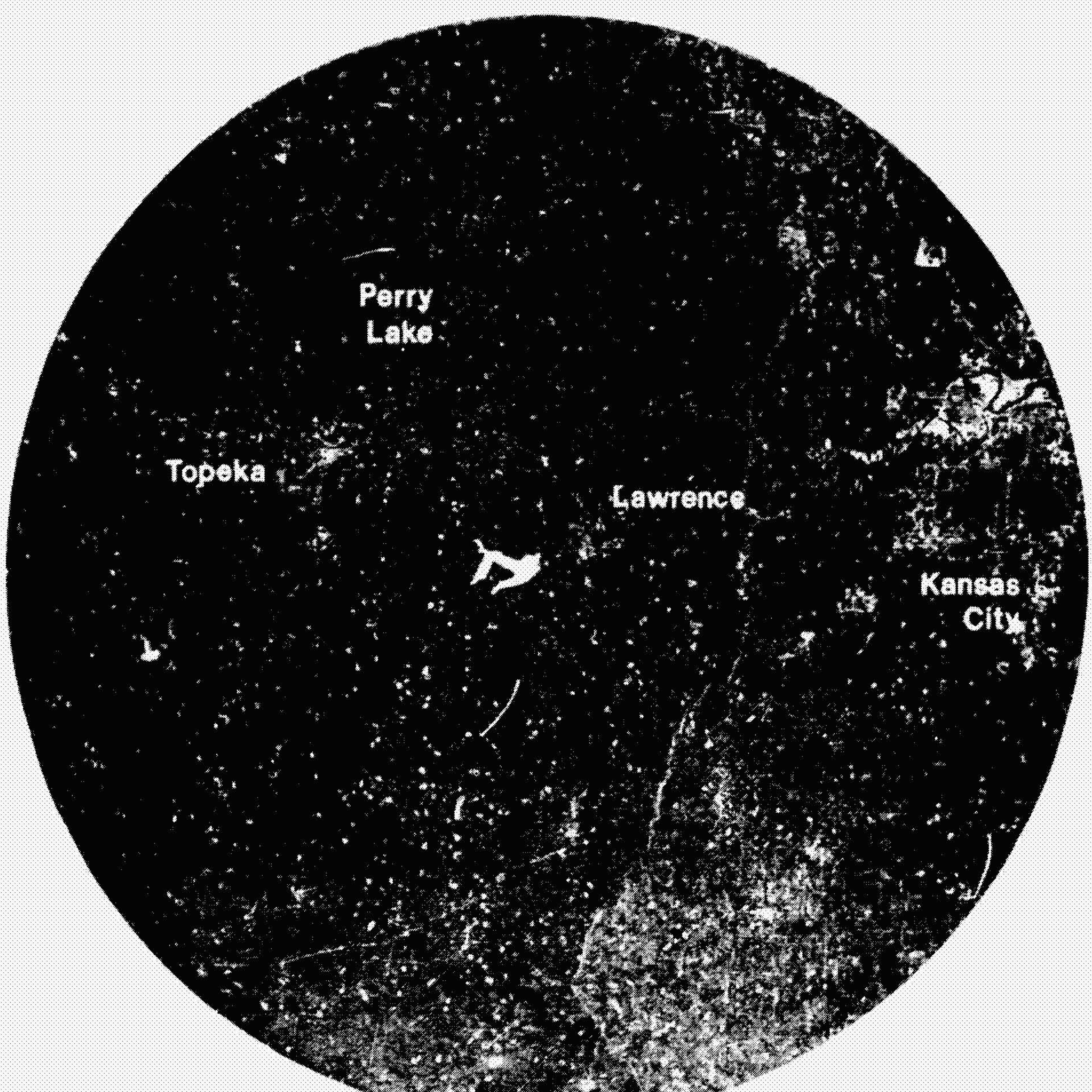


Figure 3. Location of the Clinton reservoir under construction in the Topeka-Kansas City urbanization corridor.

Figure 4. Development potential of areas surrounding Clinton Reservoir. Areas with dense woods, excellent wildlife habitat, and scenic attributes were held suitable for development.

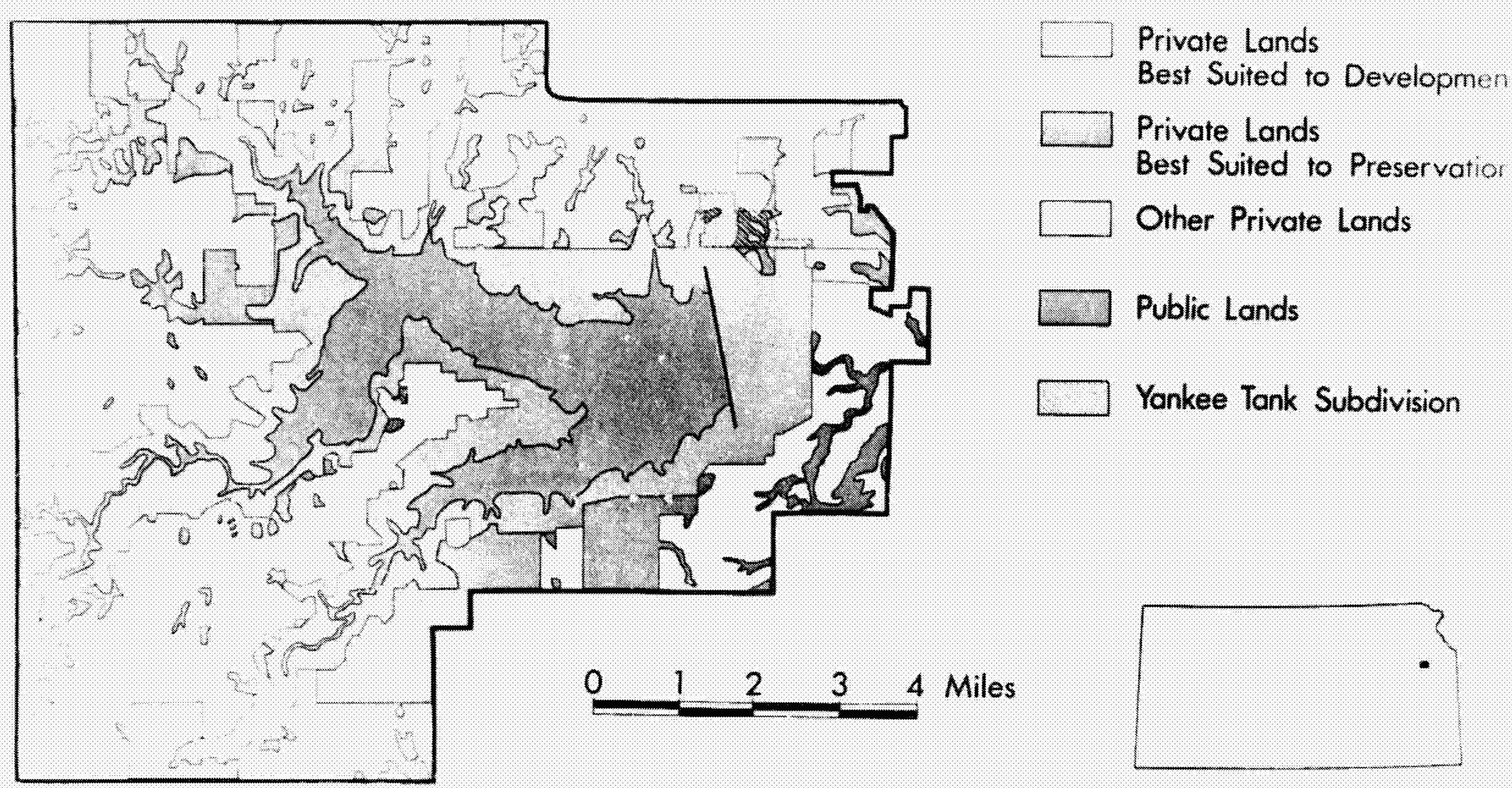
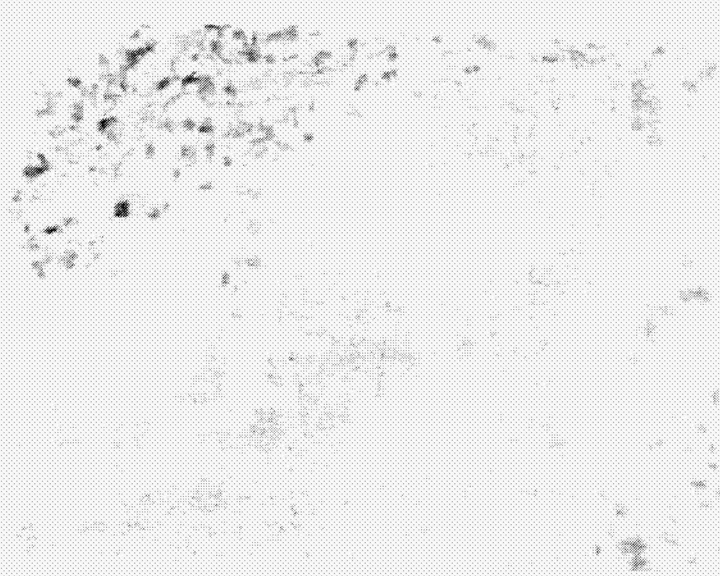


Figure 5. Installed center pivots as of Spring 1974. Note the distribution of the sprinklers relative to the two environmental factors of water availability and soil texture. The variables are related as shown in the legend.

1973



1974

Figure 6. Increase in number of center pivots in southern Finney and Kearny Counties, Kansas, from May 1973 to May 1974. In the illustrated 860 sq. km. the number of center pivots has increased by 114 units, representing 7.3 percent of the area.

Figure 7. Kansas City, Kansas and Wyandotte County as imaged by a single frame of U-2 imagery acquired in May 1974.

Figure 8. Illustrations from imagery used in projects for the Kansas City, Kansas, Department of Planning and Development.

REMOTE SENSING APPLICATIONS IN THE INVENTORY AND ANALYSIS OF ENVIRONMENTAL PROBLEMS **E-18**

By Gordon E. Howard, Jr., Environmental Protection Agency, Environmental Photographic Interpretation Center, Vint Hill Farms, Warrenton, Virginia and C. Al Waters, Jr., Environmental Protection Agency, Environmental Photographic Interpretation Center, Vint Hill Farms, Warrenton, Virginia.

ABSTRACT

The U.S. Environmental Protection Agency through the Environmental Photographic Interpretation Center (EPIC) is actively engaged in the extraction of environmentally related data from both high resolution and multispectral imaging systems. From its inception the EPIC has researched the various remote sensing systems available from both a cost effective and information content standpoint. Through interagency agreements and cooperative programs such as the NASA Aircraft Support Program imagery has been acquired in areas where EPA has operational requirements. Presently the efforts of EPIC are directed toward the inventory and analysis of many types of pollution sources both point and non-point.

INTRODUCTION

In early 1972 it became apparent to some in EPA that the sheer magnitude of the 3 1/2 million square miles to be monitored would require the application of the remote sensing techniques long used by many other government agencies. If the environmental monitoring job was to be done confidently, quickly and successfully it would have to use up-to-date remote sensor technology to augment and complement the information collected by the contact or in situ sensors. The most practical and cost effective way to launch EPA into the remote sensing field quickly was to enter into interagency agreements with other federal agencies whose missions have long involved the use of overhead imagery.

It was through the pursuit of these goals that EPA acquired from the Department of Defense a laboratory at Vint Hill Farms, Warrenton, Virginia. Also this same avenue yielded a considerable amount of photo lab and photo interpretation equipment and access to some very valuable domestic imagery files - all this at little or no cost to EPA. The Vint Hill facility was designated the Environmental Photographic Interpretation Center (EPIC) and remained the ward of the EPA Office of Monitoring Systems under the guidance of the Assistant Administrator for Research and Development. In July 1974 it became an associate laboratory of EPA's National Environmental Research Center in Las Vegas.

EPIC MISSION

EPIC was established primarily to accomplish the following objectives:

1. Obtain, reproduce, interpret and analyze domestic imagery from any and all federal film libraries,

2. Secure and maintain for EPA the expertise accruing from the highest technology in the collecting and processing of information to be used for decision making purposes,

3. Provide a focal point for the development of overhead monitoring technology as it applies uniquely to the mission of environmental protection,

4. Introduce into the operational arena, for complete and confident monitoring of the environment, the tools and techniques resulting from remote sensing research and development.

ENVIRONMENTAL PROJECT APPLICATIONS

The examples which follow represent a basic cross-section of the applications that EPIC is currently addressing. The preferred imagery of EPIC for its present requirements, is the high-resolution wide-coverage panoramic type which offers the required information content with a minimum of film surface area (fig. 1). The modified KA-80A panoramic camera scans 140° across track and delivers 130 lines per millimeter over 80% of its format of 5" x 60". A considerable amount of imagery from these high-resolution flights is in the federal film libraries and available to EPIC. It incorporates high resolution capabilities for analysis of minute details with wide area coverage, approximately 140 square miles per frame. EPIC has inhouse a total of approximately 90,000 square miles of this type coverage, all obtained to date on black and white panchromatic. Additionally as principal investigators for Skylab and LANDSAT, we use that material in all ways that apply to EPIC programs.

1. The Monongahela River Basin:

   A non-point pollution source inventory was initiated by a request from the EPA Region III Surveillance & Analysis Division. They were interested in a qualitative and quantitative inventory of such non-point sources as strip mines, junkyards, dumps, sediment producing areas and water impoundments exhibiting eutrophication. The panoramic system was a natural for this task. Additionally the National Environmental Research Center in North Carolina was interested in an R&D effort to determine the feasibility of using this imagery system to locate all potential point emission sources - smoke stacks - along the Monongahela River (fig. 1). This proved to be completely feasible from the interpretation standpoint. Figure 2 illustrates the types of categories included in the program. Figure 3 is an enlargement of the coke works of U.S. Steel at Clairton, Pa., which contains 2100 coke ovens. Figure 4 is an uncontrolled mosaic of the study area.

2. Southern Iowa Water Resources and Pollution Sources Survey:

   This program encompasses an area of eleven counties in which the Region VII office in Kansas City submitted a request for support. The ultimate consumer was the Remote Sensing Laboratory and the Department of Environmental Quality of the State of Iowa. A lack of good map bases necessitated the use of uncontrolled mosaics for inventory purposes only thus forcing us to disregard geographic and geodetic control. However, overprint lines were used to show the state users the mismatch areas. The resulting inventory sheets were very favorably received by the State of Iowa as being very useful to their desired purposes - inventorying and monitoring of environmental factors. Figure 5 is a typical example of a small private feedlot.

3. Cattle Feedlot Inventory in Nebraska:

   This study was similar in nature to the Iowa study, but the feedlots were much greater in size and capacity (Figure 6 - Manley Feedlot). The area from Stanton to West Point on the Elkhorn River was inventoried to measure the cattle waste effect on the river. Some 480 farms were located within the drainage basin along this 30 mile stretch of river. Figure 7 shows some of the larger commercial feedlot operations in this area. This was also a test study area in the National Water Quality Survey Sites program of EPA which included 67 station pairs located throughout the 10 EPA Regions in the U.S.

4. Lower Calcasieu River All-source Pollution Inventory:

   The EPA Region VI, Dallas, Hazardous Materials Division requested an all-source pollution inventory of the lower Calcasieu River in Louisiana, including Beauregard, Calcasieu and Cameron Parishes. The program consisted of locating and plotting all industrial complexes, petroleum fields, car dumps, garbage and municipal dumps and feedlots in the 3400 square mile study area. The format of the final product con-

sisted of thematic overlays keyed to 7 1/2" and 15" USGS quadrangle sheets (Figure 8).

5. Cornell University Leachate Migration Study:

In consortium with Cornell University, EPA/EPIC entered into a feasibility research study to attempt to locate, identify and map the migration of leachates from landfills (Fig. 9). The study area centers around Syracuse, New York, and is employing color infrared, conventional color and thermal sensors. To date flights have been accomplished on a seasonal basis in order to determine if and when these migrations occur and can be detected. The essential ground truth is being supplied by the Department of Environmental Conservation in the State of New York. An initial finding, using December 1974 coverage, utilizing no ground truth, displayed ten representative leachate areas detected for the first time. Of these ten, using remote sensor analysis only, six were classified as definite leachate areas, three as probable and one as doubtful. Subsequent ground truth confirmed the photo interpretation in nine of the ten areas - one of the probables being negated. This 90% accuracy rate seems to confirm at least, the feasibility of our approach for similar environmental problems in other areas of the U.S.

6. Muskegon County, Michigan Wastewater Treatment Project:

This project was suggested to EPIC by the EPA Region V support office in Muskegon. It involved the plotting of a newly integrated series of wastewater treatment processes which may serve as a prototype for areas throughout the country. After storage and disinfection of the water, with its nutrient loads, it is spray irrigated on crops, predominantly corn. The water then is filtered through the soil to an underdrainage return system and is discharged to the surface waters of Muskegon County. The entire system is monitored to assure that all effluents meet drinking standards. The secondary benefit of crop irrigation is welcomed in this area because of the lack of economic vitality in an area not noted for its agricultural accomplishments. The methodology used on this project was to superimpose Skylab imagery over prior Department of Agriculture photography to delineate the confines of the approximately 10,000 acre facility.

7. Colstrip Montana Coal-fired Power Plant Study:

This project is a cooperative effort between EPA's National Environmental Research Center in Corvallis, Oregon, the State of Montana and several universities with remote sensing support supplied by EPIC. The primary purpose of the study is to develop the expertise to predict the effects of air pollution on an ecosystem by analyzing the ecological condition of an area <u>before</u> the introduction of a pollution source and comparing, on a periodic basis, the stresses exhibited over a period of four years after production is generated. A request for NASA aircraft support has been made and accepted by NASA Ames for mid to late 1975, utilizing a panoramic imaging system at high altitudes. Other imagery will be acquired through the State of Montana with reproduction services and analysis performed by EPIC. It is anticipated that the results of this study will provide an excellent photo interpretation key for the assessment of environmental impacts and compliance monitoring.

8. Technical Support to the City of Chicago, Illinois:

Through the efforts of the Regional Counsel of Region V EPIC and the Remote Sensing Branch of the Monitoring Applications Laboratory of NERC, Las Vegas were asked to analyze a Skylab photograph of the Chicago metropolitan area (fig. 10). The intent was to enter the analysis into evidence in a court case involving the City of Chicago versus a major steel producer.

The first phase of the program involved providing expert testimony in the interpretation of a "plume" seen on the photo and providing an approximation of its extent. This was accomplished on May 1, 1974.

The City's case contended that the discharging plume from the Indiana Harbor Ship Canal was entering the intake of the Chicago water supply. This would conceivably occur under the proper wind and current conditions of Lake Michigan. However, the plume exhibited on the Skylab photo was curling in the wrong direction for use as direct evidence.

It was felt by the on site EPA personnel that, given the proper wind and current conditions, it would be advantageous to overfly the discharge area using a thermal infrared scanner. As a result a NERC Las Vegas aircraft and sensor crew were dispatched to Chicago and the overflight was accomplished. The imagery obtained clearly showed that the waters of the canal had shifted and were heading toward the water intake.

Further testimony was presented to the court and the thermal images and a deposition were entered into the prosecution's case.

SUMMARY

To date, in its brief 1 1/2 year existence, EPIC has found that the nature of its requirements has almost exclusively demanded the use of high resolution photography. Our requirements run the gamut from long term programs such as the development of environmental photographic interpretation keys and the stresses introduced into the ecosystems by man made changes in the environment to the detection, indentification and analysis of cattle and swine feedlot operations.

In some of our other studies we have used combinations of simultaneously acquired imagery. In a study of a series of sanitary landfills, conventional color, color IR and thermal scanner imagery are being used in a research effort to detect and study leachate migration from the landfills.

In some of our Fiscal Year '76 projects, we have been fortunate enough to have four programs approved for high altitude panoramic imagery acquisition by NASA using the KA-80A camera system. The EPIC Director, Mr. Vernard Webb, is a Principal Investigator for LANDSAT and Skylab imagery and EPIC has been able to utilize all the Skylab imagery available. We use this imagery to the extent possible in accomplishing our mission.

EPIC's most valuable operating asset is its wealth of interagency agreements. This saves us the cost and unnecessary loss of time which would be expended in starting our operation from square one. It is also very important to us to have a high level of experience in our photointerpreter/analysts and a multidisciplinary academic background.

Figure 1.- Monongahela River non-point inventory.

MONONGAHELA RIVER BASIN

NON-POINT SOURCE POLLUTION INVENTORY

PARAMETER	DATA REQUESTED
Junk car dumps	Location
Strip mines, active and inactive	Location and size
Strip mines spoil areas	Location and size
Acid mine drainage discharges	Location
Solid waste dumps	Location
Sediment producing areas	Location and size
Timber cutting areas	Location
Mine tailings impoundment dams	Location
Industrial effluents	Location
* Eutrophic impoundments	Location
* Thermal effluents	Location

* limited returns - additional imagery required

Figure 2.- Categories included.

Figure 3.- Clairton Coke Works in Pennsylvania.

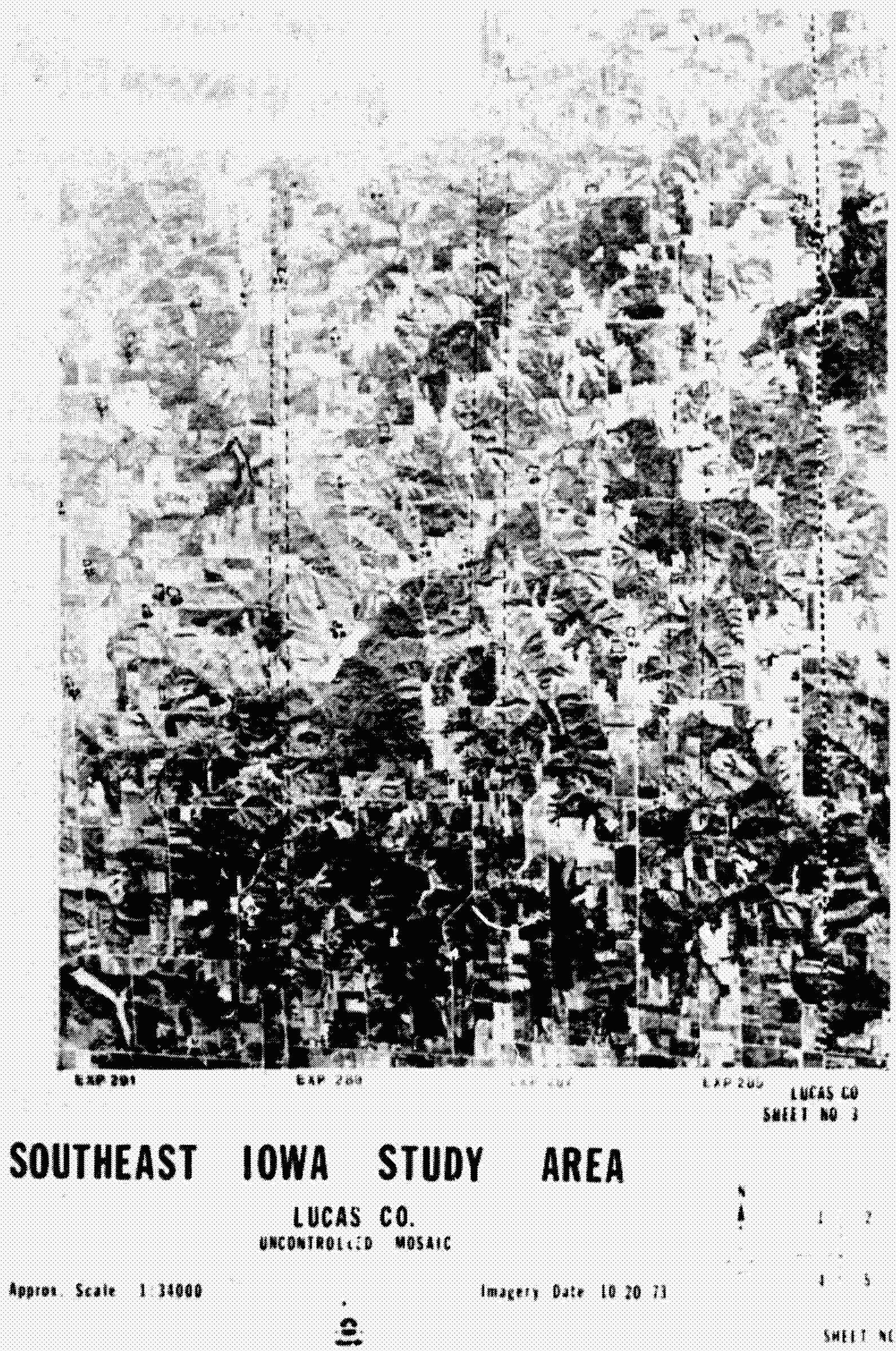


Figure 4.- Example of uncontrolled mosaic in Iowa study.

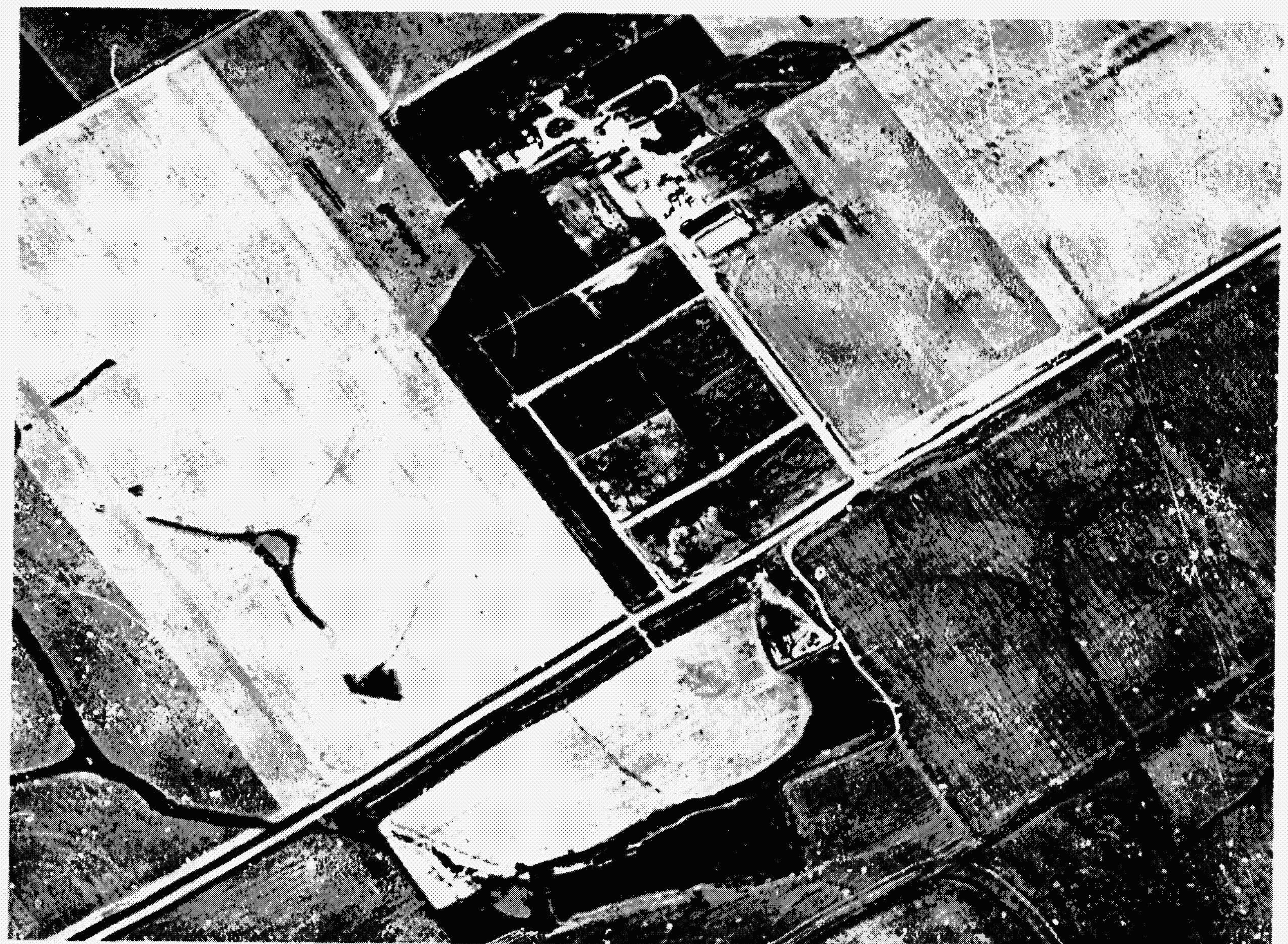


Figure 5.- Small cattle feedlot in Iowa.

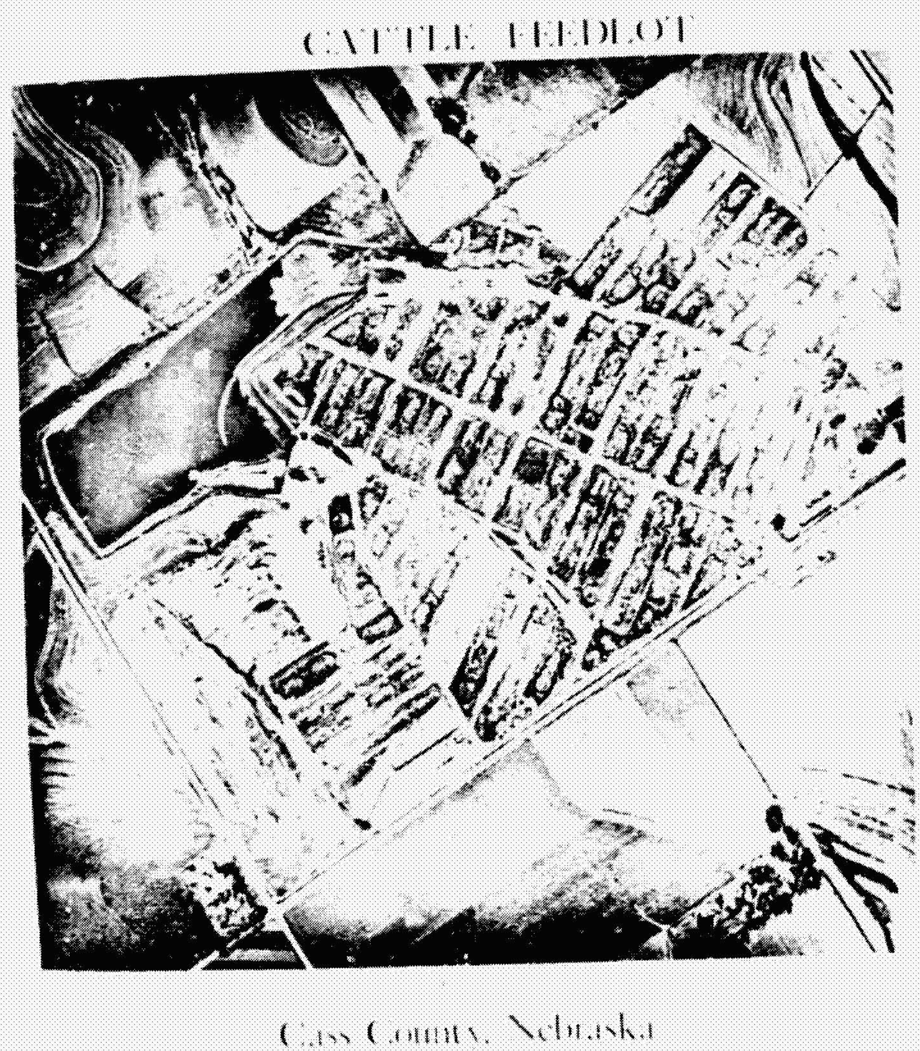


Figure 6.- Manley commercial feedlot, Nebraska.

Figure 7.- Examples of feedlots between Stanton and West Point, Nebraska, on the Elkhorn River.

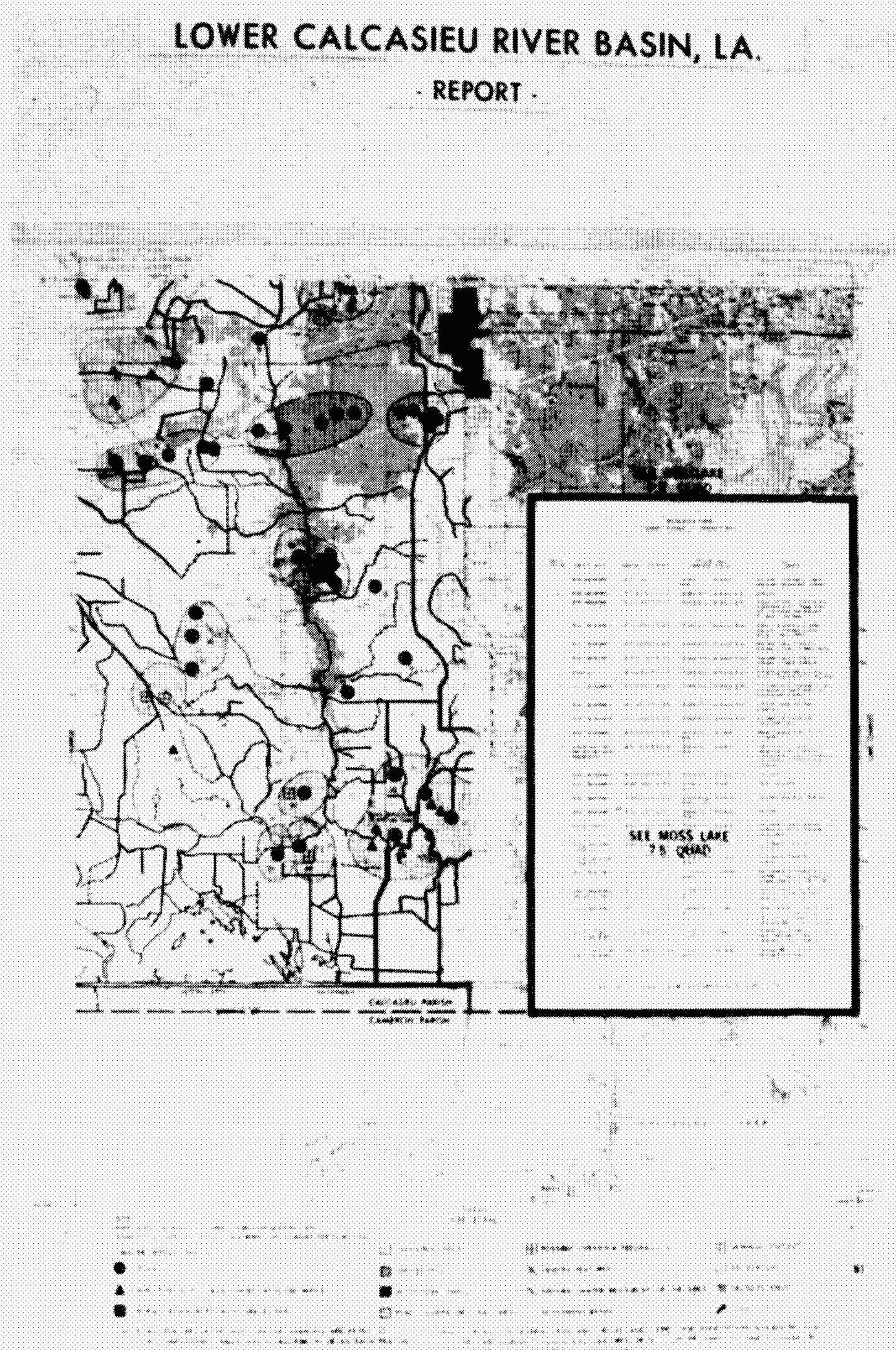


Figure 8.- Example of Calcasieu River pollution inventory.

MOSAIC - CONVENTIONAL COLOR - 1254 HRS. - ALT 2,500 AGL

Prepared by

MOSAIC - I.R. COLOR - 1254 HRS. - ALT 2,500 AGL

Figure 9.- Example of imagery used in Cornell study.

Figure 10.- Skylab image of Chicago area.